Map-based decision support tools for collaborative land use planning

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Map-based decision support tools for collaborative land use planning

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Gustavo Alonso Arciniegas López

geboren te Bucaramanga, Colombia

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Gustavo A. Arciniegas López

Amsterdam, September 2012

Contents

Chapter 1

Introduction

1.1. Challenges of spatial planning: decision support tools for multi-actor collaboration

Human activities have played a fundamental role in shaping our planet to its current state. In particular, the modification of natural environments into built environments has had a major influence on how the planet has changed over the centuries. The practice of agriculture, especially the domestication of wild animals and the cultivation of plants for food and fiber production, has been argued to have been primarily responsible for the establishment and rise of sedentary human civilizations (Diamond, 1997). Since the rise of agriculture around some 10,000 years ago, the size of human population has increased to roughly seven billion and is expected to reach ten billion by the end of this century (UN, 2010). About 30-40% of the planet's ice-free land is currently used by humans, with over 38% of that land being used for agricultural practice. The impact of human activities on the planet's ecosystems has been so profound that there is currently a debate among geologists about defining a new geological era characterized by human effects on the geological record (Jones, 2011). This new period, labeled the 'Anthropocene era' by Nobel laureate Paul Crutzen, would have started in the late eighteenth century, following on from the Holocene, which to this day officially continues as the current era (Crutzen, 2002).

In light of the above, space has undeniably become a key resource for the development of human activities around the world, particularly in densely populated areas where it is becoming increasingly scarce. According to the Council of Europe Conference of Ministers Responsible for Spatial/Regional Planning, spatial planning refers to the methods and tools used by the public sector to organize the distribution of human activities across territories of different scales according to an overall strategy and directed towards a balanced development and a physical organization of space. Within spatial planning, there are a number of professional disciplines dealing with specific aspects of planning, such as land use planning, urban planning, regional planning, transport planning, marine planning and environmental planning. Together, these disciplines constitute support mechanisms for the achievement of societal goals about sustainable growth, biodiversity preservation, environmental quality and amenity (UN, 1987).

The escalating effects of human activities on the global environment, in combination with major environmental changes such as climate change, greatly influence how societal goals can be organized spatially for the centuries to come. Achieving environmental, social and economic sustainability for an increasingly populated planet with limitations of space and natural resources remains a challenge that entails many disciplines, including spatial planning. Developing spatial plans to facilitate the allocation of human activities across a territory requires choices and decisions and a careful balancing of short-term and long-term needs, for example as to what natural areas to protect or how to organize several functions in the same space. Multi-disciplinary research approaches have emerged to provide integrated assessments that can be useful for decision-makers and other societal actors of a spatial planning process (de Ridder et al., 2007). Computer-based collaborative planning systems also constitute an interesting approach for increasing access to relevant information in collaborative planning settings in the form of tools, group cognition and media (Shiffer, 1992). However, there is still a need for solid approaches to collaborative spatial planning between various types of actors in order to respond to the requirements of sustainable development and nature protection and to guarantee maximum social benefits without degradation of natural resources. More specifically, there is a need for tools to help bring to light and negotiate the trade-offs between the management of natural resources, agricultural interests and sustainable development. To date, such tasks still prove challenging for scientists and engineers in charge of guiding society towards an environmentally sustainable form of spatial management.

A simple example of a tool for collaborative spatial planning

In simple terms, planning can be viewed as the process of defining and organizing the steps and activities required to achieve a desired outcome. When multiple ‘planners’ are involved in a planning situation, this may be called a collaborative planning process. In such a process, planners are required to work together, make collective decisions and communicate with each other while performing activities to accomplish shared goals. Collaborative planning processes are frequently found in daily life. For example, a couple moving into a new empty house wants to buy pieces of furniture and place them in different locations of the house. Planning these tasks may require collaboration between the two people and perhaps support tools. Tasks such as choosing the furniture and defining the order in which each piece should be moved into the house require the couple to decide together what to buy and the location of each piece across the house. Support tools can be simple, like a pen and a notepad to write down a list of items to buy, measuring tape for retrieving distances of the rooms. More complex tools can include a computer connected to the internet for searching and locating stores and comparing stock and prices.

The particular case of planning the distribution of furniture across the house space requires relatively more complex planning tools because planners must deal with locations, distances, areas or even volumes. Defining and organizing collaborative tasks that involve spatial locations in order to achieve an outcome can be referred to as collaborative spatial planning. If the outcome involves individuals working in a group to solve a spatial decision problem, this can be termed collaborative spatial decision-making. Relevant support tools can be referred to as collaborative spatial decision support tools. In general terms, maps can be powerful planning tools often used to support collaborative spatial decision-making (Kraak and Ormeling, 2003). Imagine a large-format topographic map unfolded on a table and four individuals discussing around it, pointing at locations, estimating distances, discussing area sizes. A road map, for example, can provide great help to travelers when planning a route to a destination. Hence, maps are collaborative decision support tools in their own right.

Referring back to the example of the couple and the furniture, a printed version of the house plan can play the role of a collaborative planning support tool. Alternatively, the couple may decide to use relatively sophisticated tools like computer-based virtual house planners, such as Sweet Home 3D (http://www.sweethome3d.com/) or Google SketchUp (http://sketchup.google.com/), or online room designers such as Autodesk Homestyler (http://www.homestyler.com/). For example, with Sweet Home 3D or Autodesk Homestyler, users can quickly drag and drop furniture elements and position them across a 2D house layout to make a plan of the house interior (Figure 1.1). These plans can be measured and visualized on the computer screen in 3D. Plans can be shared and multiple users can collaborate on the same plan. The tools provide quantitative feedback in the form of areas and volumes utilized as well as plan costs and a list of furniture items with dimensions and other specifications.

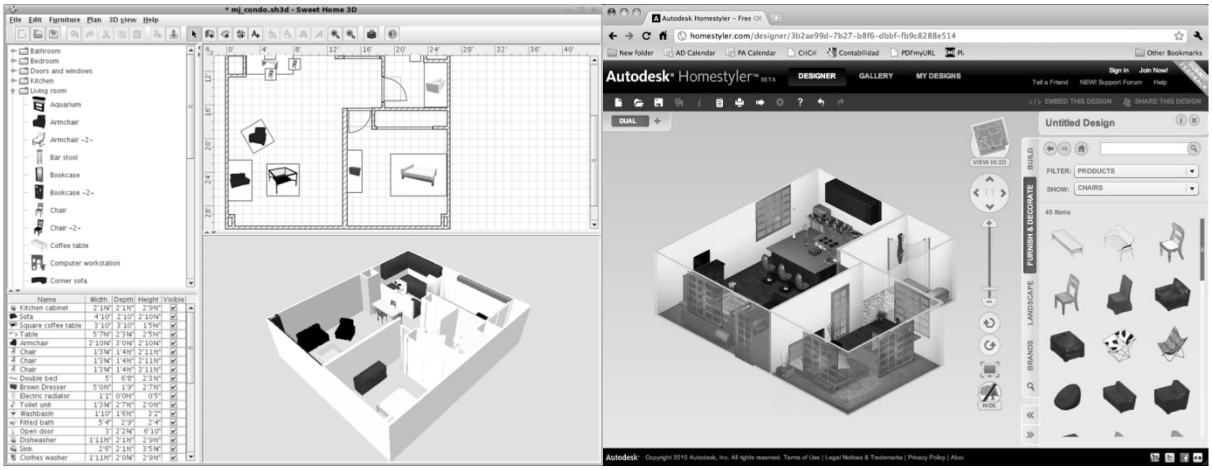


Figure 1.1. Screenshots showing the interfaces of the tools 'Sweet Home 3D' and Autodesk Homestyler for interactive house interior planning.

Collaborative map-based decision support tools similar to Sweet Home 3D can also be useful tools to define, organize and regulate the development of land within a territory, regardless of its size, i.e. they can be applied to land use planning. Land use planning constitutes a good example of a planning process with multiple 'planners' involved, or decision-makers, who need to work together and communicate with each other with the purpose of organizing human activities and developments within a given territory. This thesis is about map-based decision support tools (development, implementation, testing and application) for collaborative land use planning. It aims to develop a methodology that includes a set of such tools that facilitate collaborative work around digital maps and that can be applied in a land use planning process.

The reason for the 'map-based' label is that maps in digital form (i.e. digital maps) are a central aspect of the tools. A digital map is defined in this thesis as a virtual representation of spatial data regarding a geographic area or a phenomenon that can be organized, displayed or analyzed by a computer, and more specifically by a Geographical Information System (GIS). Digital maps constitute the main information source for the tools developed for this research. Maps are used as input for the tools, are combined, processed and transformed to communicate feedback information, and are used to present outputs.

1.2. GIS and collaborative decision making

The use of digital maps in planning practice is not always an easy task for most users, particularly when used as collaborative tools (Kraak and Ormeling, 2003; Carton and Thissen, 2009). Planning tasks that involve the use of maps as a means to retrieve spatial information can be facilitated with GIS. Geographic information science deals with the theory behind the development, use and application of GIS and includes a number of research areas that focus on different approaches to GIS. As planning processes become more complex, GIS have been integrated with other support tools that focus on structuring and addressing decision problems, such as tools for Multicriteria Decision Analysis (MCDA) (Belton and Stewart, 2002). This particular integration has given rise to a range of tools known as Spatial Decision Support Systems (SDSS). According to Malczewski (1999), an SDSS is a "computer-based set of tools designed for supporting a user or group of users in achieving higher effectiveness of decision-making while solving a semi-structured spatial problem".

The ways in which SDSS have been used for spatial planning processes has changed over the last decades. In general they have been increasingly developed for groups rather than for individual users as a result of a shift from technocratic to more participatory approaches, creating a need for collaborative tools. This, together with a broadened use of GIS and the internet, has led to the emergence of a variety of tools for collaborative spatial decision-making known as Participatory GIS (PGIS). Within geographic information science, the 'GIS and Society' area addresses particularly GIS implementations in relation to the different societal contexts in which GIS are applied (Pickles, 1995). According to the GIS and Society literature, PGIS belong to the societal GIS implementations that deal with the effective use of GIS technology by groups in the context of collective planning and decision-making (Jankowski, 2009). Figure 1.2 illustrates the societal implementations of GIS under the umbrella of the GIS and Society research area.

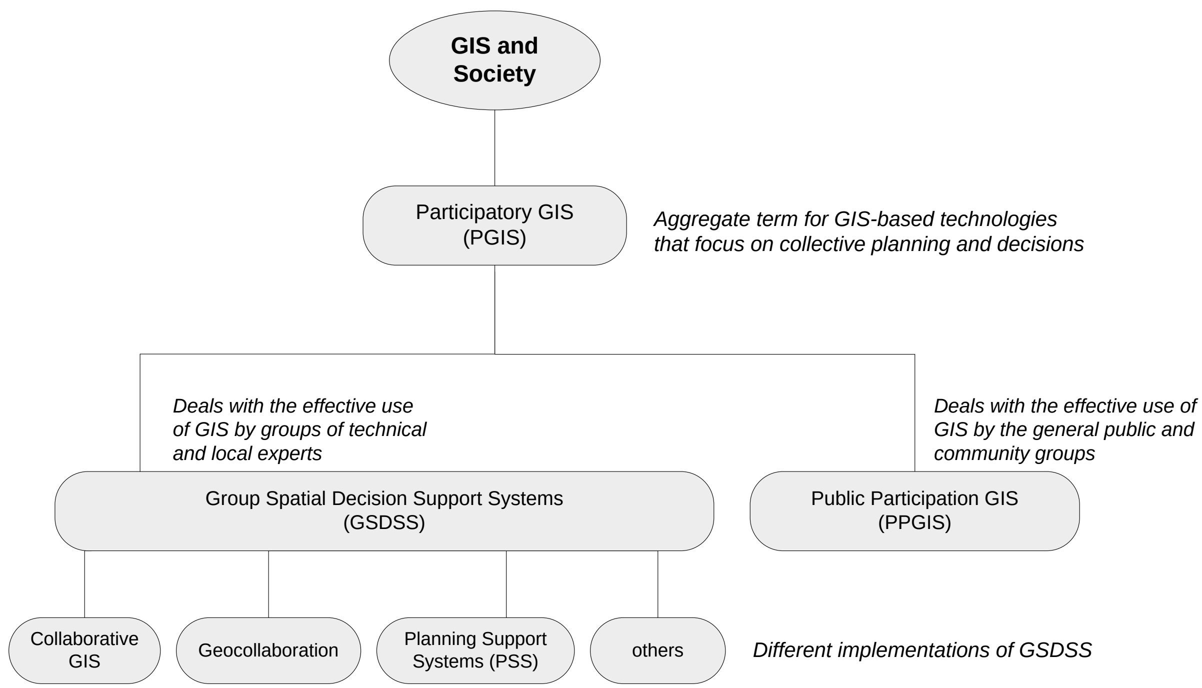


Figure 1.2. Positioning systems for collaborative spatial decision-making within the GIS and Society research area (adapted from Balram and Dragicevic, 2006).

One of the first reported applications of PGIS took place in the mid-nineties and involved community mapping to discuss local and regional landscape issues in South Africa (Harris et al., 1995). Since then, PGIS has evolved roughly along two major paths that focus on issues of human participation within group spatial decision-making: GSDSS and Public Participation GIS (PPGIS). GSDSS includes tools designed to support a group or different groups of users in addressing ill-defined spatial decision problems (Armstrong, 1994). PPGIS addresses the effective use of GIS technology by the general public and community groups in planning and decision-making for their communities, establishing different levels of involvement of the citizens and marginalized groups (Craig et al., 2002). An important distinction between these two directions is that GSDSS focuses on systems and tools, whereas PPGIS gives more attention to the involvement of the public, their access to GIS and maps, and the incorporation of their preferences and relevant experience. This thesis pays particular attention to those tools that fall under the GSDSS category.

Recent implementations of GSDSS have been classified in the GIS and Society literature according to the specific goals of the system and the decision-making context. Relevant to this thesis are implementations known as Collaborative GIS, Planning Support Systems (PSS), and Geocollaboration approaches, among others. Collaborative GIS integrates theories, tools and technologies of geographic information science with capabilities to support group decision-making (Balram and Dragicevic, 2006). PSS focus on the incorporation of GIS and analytical models to support specific tasks of planning processes (Geertman and Stillwell, 2009). Geocollaboration comprises approaches to integrate geographic visualization, analytical tools, human-computer interaction and GIS to support spatial decision-making among multiple actors (Andrienko et al., 2007).

In addition to this gradual emergence of support systems and the widened use of internet technology, a new generation of hardware developments has been incorporated into GSDSS. Interconnected computers, decision rooms, touch-enabled screens, location-based systems, personal digital assistants, smart phones and tablets are increasingly being included into the design of the GSDSS to support multiple users in executing planning tasks. A pioneer example of such tools was the system called Paint the Town™ (Dieber, 2003), which included a GIS software package and a drawing tablet and allowed users during public meetings to allocate land uses and draw urban growth boundaries. The software then calculated different scenarios, for example for population and employment.

1.3. Current use of spatial tools for collaborative decision-making

It is clear that there is a growing integration of research areas, tools and technologies within collaborative spatial decision-making. Despite all of these developments, and this promising integration of technologies, the current number of successful implementations of such systems in real planning practice is still low and such studies are seldom reported (Geertman and Stillwell, 2009). There are two major reasons for this limited use of support systems in practice, which have been discussed in the academic literature: 1) the mismatch between users and support systems; and 2) an inadequate process-specific support by these systems.

The mismatch between users and systems relates to the question whether systems really support collaborative work between users and are designed to be used collectively. For example, an off-the-shelf SDSS or a GIS package designed for single decision-making that is used during a meeting by multiple users can be wrongly regarded as a collaborative decision support system. Spatial tools for collaborative decision-making should facilitate the interaction and communication between system users as well as the interaction between these users and the system itself. In addressing this issue, Vonk et al. (2007) proposed improving communication and cooperation between system developers and end-users while the systems are still under construction. Supporting collaborative decision-making should involve supporting communication, transfer and processing of knowledge from stakeholders, whether locals or experts. Furthermore, supporting collaborative work should include supporting interactions between end-users who may have different, even opposite, views and goals with regards to the planning process. This issue is common in land use planning and water management, both of which have seen an evolution of stakeholder involvement over the decades in the form of a shift from communication to active participation and collaboration for conflict solving and consensus reaching (Pahl-Wostl, 2005). To date, current systems still feature an unclear support for group work and collaborative tasks among conflicting planning goals (Dragicevic and Balram, 2006). These would require end-users to test system prototypes in close communication with developers, as well as structured tests of success and effectiveness of these systems. Solid guidelines for the evaluation of system effectiveness that utilize users' opinions and experiences with the system as well as objective tests and measurement can also contribute to addressing this issue (Nyerges et al., 2006).

The fact that many current systems still provide inadequate process support can be associated with a mismatch between systems' information outputs and the specific goals of stages of the decision-making process: technology-driven systems produce the correct answer to the wrong question at the wrong moment (Uran and Janssen, 2003). This support relates directly to the type and format of information that users are provided with and that is specific to an individual decision-making stage. This includes how this information needs to be presented, processed and used according to the goals of that particular stage as well as the target users and the level of both detail and complexity of this information.

In addition to supporting individual stages, systems should also be able to support the whole decision-making process. This means supporting not only the goals of each individual stage, but also the feedback loops between theses stages (Malczewski, 1999). The following section presents the goals of this thesis, focusing on how to address the issues mentioned above in building interactive map-based tools that support collaborative work and that can be put into practice to support land use planning processes.

1.4. Research objectives and scope

The major goal of this thesis is to develop and implement a methodology that incorporates map-based tools into a land use planning process with conflicting objectives of stakeholders. This goal is reached by addressing the following four research objectives:

1. To develop, implement and test a set of spatial tools that support the integration of stakeholder knowledge for designing and evaluating land use plans (Chapter 2)

2. To develop, implement and test a negotiation tool that supports collaborative allocation of land use amidst conflicting objectives (Chapter 3)

3. To analyze the effectiveness of map-based collaborative tools for land use planning (Chapter 4)

4. To apply the tools to planning processes in a collaborative workshop setting. This includes two applications in practice within two case studies for land use planning (Chapter 5) and marine spatial planning (Chapter 6).

Scope and limitations of this thesis

The notion of map-based tools for collaborative planning is broad. Any spatial tool that is used to support group discussions about spatial issues of any given area can fit in this label. For example, maps of different phenomena in digital or printed format can be map-based tools and can also be applied to support collaborative tasks in land use planning. Web maps, such as those presented in Google Maps, Google Earth or Bing Maps, or web-mapping applications, such as Google Map Maker, among several others, could also be regarded as map-based tools and still prove useful for land use practice, especially when users are to collaborate from different locations. Any GIS, whether it be internet-based or not, is also an obvious example of a map-based tool that can be used collaboratively; these are extensively employed in land use planning and spatial planning in general. Simulation tools that generate output scenarios in the form of digital maps (for example land use models, transport or hydrological models) can also be seen as map-based planning tools. This section explains the meaning of the 'map-based tools for collaborative planning' notion as explored in this thesis in order to clarify which types of tools are explored and the domain to which the tools are applied.

This thesis deals with the development of tools involving digital maps that are displayed in an offline GIS. Hence, maps provided in non-digital format, such as maps printed on paper or 3D scale models are not included in the developed tools. Likewise, tools designed to be used within a web-based GIS are also excluded. Relevant information in the form of digital maps constitutes input and output for the tools developed for this research. Input can originate from different sources and represents knowledge of stakeholders. The tools weigh and integrate knowledge in the form of digital maps, then process and transform this information in order to make it suitable for use in collaborative spatial decision-making. Therefore, the tools are intended to be used collectively by multiple users. This excludes single-user software or tools that are intended to support single decision-making.

The tools developed for this research are interactive and meant to be used in a workshop setting. The former means that tool users are allowed to provide input and generate output in real time through easy-to-use multi-user interfaces. The latter implies tasks that are to be executed by multiple users at the same time and location. This same-place-same-time setup is regarded in this thesis as a workshop setting for group spatial decision-making. Although interactive and widely used in collaborative spatial planning, neither computer simulation tools nor tools that support the creation of simulated scenarios for a particular system that has been defined using mathematical models are explored in this thesis.

The application domain of the tools used in this thesis includes the organization and spatial distribution of human activities and sustainable developments within an area, whether that area is terrestrial or marine. Regarding the scale of the application domain, this thesis is about tools for collaborative planning at a local/regional scale. This entails study areas larger or equal in size to an individual city or town but smaller than a province, state or nation. The motivation behind this choice of scale is that at such a scale, the tools can become meaningful for collaborative planning because stakeholders possess local knowledge about the study area and thus have a feeling with the maps involved.

1.5. Research approach

This section describes the general strategy to address these research objectives. The approach comprises three interrelated elements, namely the map-based decision support tools, a hardware instrument called 'the Touch table' and collaborative face-to-face policy workshops. The Touch table is a large touch-sensitive screen that works as a common map interface to support multi-stakeholder dialogue and user-map interaction. The Touch table allows simultaneous input from a maximum of four users, who touch the table with their fingers to interact with maps in numerous ways. These include navigation purposes, such as zooming in or out, panning, toggling map layers on and off and drawing comments and annotations on a map. Other tasks such as changing weights, providing input or changing the land use of one or more parcels can also be performed by touching on the table. Within the context of this approach, a policy workshop is a meeting in which stakeholders gather to discuss issues related to the use of an area or region. In the workshops, stakeholders work together on the same map using map-based tools linked to the Touch table. The main rationale of the approach is that specific map-based decision support tools can be linked to the Touch table, evaluated and then implemented in collaborative workshops that are held at various points of a land use planning process. Stakeholders gather around the Touch table and use the tools collectively in order to design and evaluate land use plans. Figure 1.3 illustrates the connections between the three elements of the research approach, namely support tools, the Touch table and collaborative workshops.

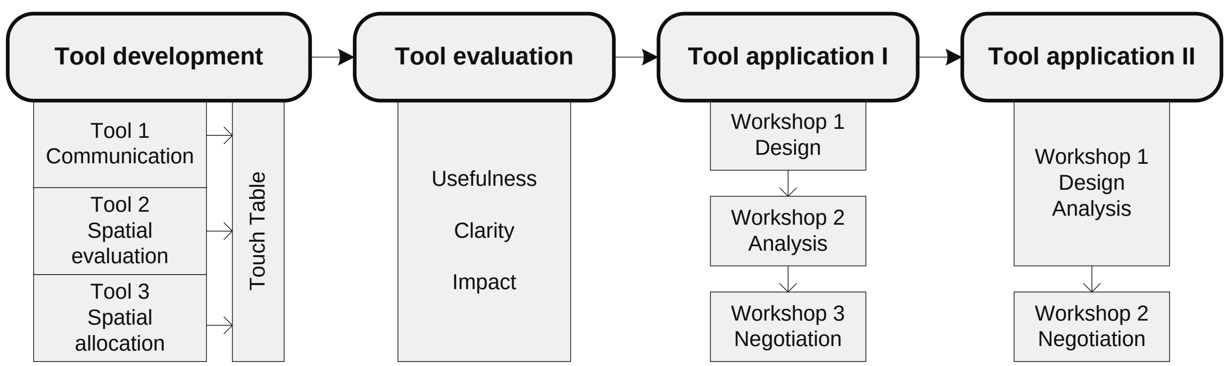


Figure 1.3. Research approach

The present research approach was carried out in four major steps: 1) tool development (Chapters 2 and 3); 2) tool evaluation (Chapter 4); 3) tool application I in three workshops within a first case study (Chapter 5); and 4) tool application II in two workshops within a second case study (Chapter 6). The first step, '*tool development*', dealt with the first two research objectives and involved three types of map-based tools, namely labeled drawing tools for communication, spatial evaluation tools and spatial land use allocation tools. The three tools were implemented in a GIS displayed on the Touch table. The first two tools support the communication and integration of stakeholder knowledge for design and evaluation of land use plans, respectively (first research objective addressed in Chapter 2). The drawing tools support the qualitative evaluation of land use plans by stakeholders in a collaborative environment. The evaluation tools support the quantitative evaluation of land use plans by multiple stakeholders on the Touch table. Spatial Multicriteria Analysis (MCA) was used in combination with expert knowledge and output of computer models to structure a decision problem in a number of criteria and facilitate the spatial and numerical evaluation of relative and overall plan qualities. The third tool supports the collaborative allocation of land use and utilizes spatial MCA to identify and negotiate trade-offs between stakeholder objectives (second research objective addressed in Chapter 3). Trade-off information is displayed on a land use map and is provided to stakeholders to support the spatial allocation of land use on the Touch table. The tool also measures in real time the effects of these changes in land use.

The second step, '*tool evaluation*', addressed the third research objective and dealt with the empirical evaluation of the effectiveness of the tools developed for this research (Chapter 4). In addressing this objective, the effectiveness of the tools was first assessed empirically and then analyzed statistically. By having M.Sc. students play stakeholder roles and carry out the workshop assignments in a controlled environment, it was possible to assess and compare tool effectiveness on the basis of tool usefulness, tool clarity and impact of tool on the decision process.

Third and fourth steps, '*tool implementation I and II*', addressed the fourth research objective, which concerned the application of the tools developed for this research to two case studies: firstly to the land use planning process of a peat-meadow polder in the Netherlands (Chapter 5); and secondly to the marine spatial planning process of an off-shore tidal energy site in Scotland (Chapter 6). The tools were implemented in a series of collaborative policy workshops organized with stakeholders of each planning process. The workshops were categorized into a sequence of three types, namely design, analysis and negotiation. The design workshop takes place in the beginning of the decision process and is followed by an analysis workshop. The negotiation workshop takes place near the end of the decision process. Each workshop involves a specific type of map-based tool.

Novel aspects of the research approach

The research approach discussed in this thesis features a number of innovative aspects. A first aspect is the incorporation of a multi-user state-of-the-art instrument like the Touch table in policy making. In the last few years there has been a rapid increase in the production and commercialization of devices that implement multi-touch technology to handle digital content. As such technology rapidly becomes commonplace, this thesis proposes an innovative approach to apply it to multi-actor policy planning processes. This is reached by building tools that couple such instruments with spatial information and existing models, such as an MCA evaluation model in order to prompt knowledge transfer and support consensus reaching.

A second aspect is the possibility to explore different methods to properly assess the effectiveness of tools that are used for spatial policy making. This aspect is significant since many support systems have already been and continue to be developed, yet their capabilities to actually produce desired results in real practice are seldom demonstrated. A third aspect is the demonstration of the versatility of the proposed methodology in its applicability to two very different domains of policy making, such as land use planning and sustainable marine spatial planning. A fourth aspect is the integration and incorporation of stakeholder knowledge, whether it is local or expert, into a spatial decision-making process. This thesis offers a clever combination of map-based tools, the Touch table and three different types of workshops whose applicability can be extended to a range of policy making processes that require the integration of stakeholder knowledge among conflicting objectives.

1.6. Thesis outline

This thesis consists of seven chapters. The thesis outline is shown schematically in Figure 1.4.

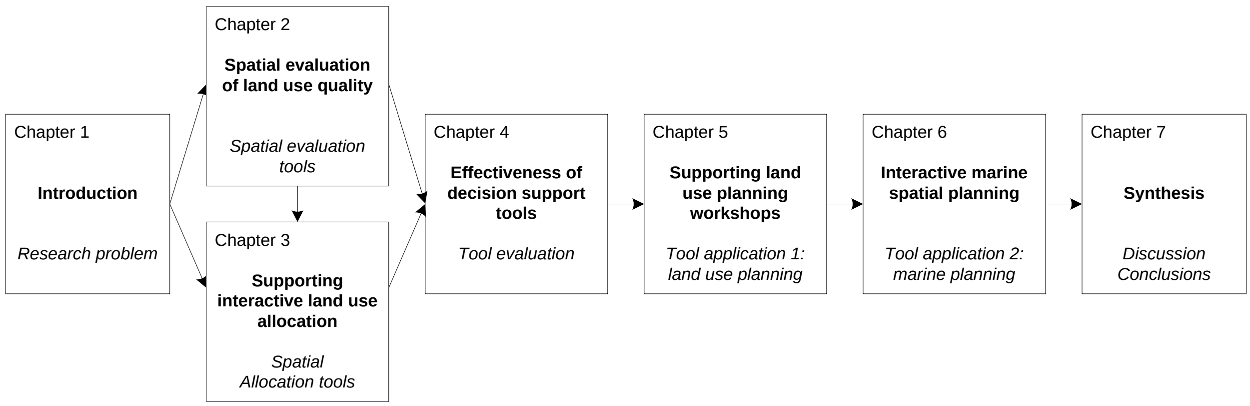


Figure 1.4. Flowchart of chapters of this thesis.

Chapters 2 to 6 are based on five research articles, which are published or accepted for publication in international peer-reviewed scientific journals. Chapters 2 and 3 describe the technical design of the support tools developed in this research and demonstrate their use with stakeholders of the land use planning process of a Dutch peat-meadow area called the Bodegraven polder. Chapter 2 presents a tool that combines GIS, MCA and expert knowledge for the evaluation and comparison of land use alternatives. The tool was tested with researchers involved in the planning process of the polder, in which they used the tool collectively on the Touch table to numerically assess and rank a number of land use alternatives. The chapter ends with a discussion on the combined use of expert knowledge and MCA in a workshop setting. The tool presented in Chapter 2 is extended with capabilities for trade-off identification, negotiation and land use allocation in Chapter 3. The use of the tool is demonstrated in a workshop with stakeholders, followed by a discussion on the use and limitations of the tool.

Chapter 4 deals with the empirical analysis of the effectiveness of the tools presented in Chapters 2 and 3. It presents an approach to assess, analyze and compare the effectiveness of these types of tools in qualitative (perceptions) and quantitative (observed measurements) terms. The experiment was carried out using university students of an M.Sc. program as test subjects.

This research approach includes a series of three different workshops, beginning with a design workshop, followed by an analysis workshop, and ending with a negotiation workshop (see Figure 1.3). The application of the tools in three workshops, as well as their incorporation into the land use planning process of the polder, is the subject of Chapter 5. Chapter 6 describes the application of the tools developed for this research within the context of a marine spatial planning process. This chapter demonstrates both the use of the tools and their implementation during two stakeholder workshops to gather data, evaluate spatial effects and facilitate reaching of consensus for the spatial allocation of sites for tidal renewable energy off the Mull of Kintyre, Scotland.

Finally, Chapter 7 summarizes the findings of this thesis and discusses these findings in the context of each research objective formulated in Chapter 1. Main conclusions of this research are then offered together with a number of relevant implications for land use planning and spatial planning in general. In the last part of the chapter, a list of recommendations for future research ends this thesis.

1.7. Publications related to this thesis

Research papers in international peer-reviewed scientific journals:

- Alexander, K.A., Janssen, R., Arciniegas, G.A., O'Higgins, T.G., Eikelboom, T., Wilding, T.A., 2012. Interactive Marine Spatial Planning: Siting tidal energy arrays around the Mull of Kintyre. PLos ONE, 7(1): e30031. doi:10.1371/journal.pone.0030031.
- Arciniegas, G.A., Janssen, R., 2012. Spatial decision support for collaborative land use planning workshops. Landscape and Urban Planning 107(2012), 332-342.
- Arciniegas, G.A., Janssen, R., Omtzigt, N., 2011. Map-based multicriteria analysis to support interactive land use allocation. International Journal of Geographical Information Science, 25(12), 1931-1947.
- Arciniegas, G.A., Janssen, R., Rietveld, P., 2012. Effectiveness of collaborative decision support tools: results of an experiment. Environmental modelling & Software (2012), doi:10.1016/j.envsoft.2012.02.021.
- Janssen, R., Arciniegas G.A., 2010. Gebruik van een interactieve kaarttafel bij participatieve planprocessen (Using an interactive Touch table in collaborative planning processes). Landschap 3(27), 183-188. [in Dutch]
- Janssen, R., Arciniegas, G.A., Alexander, K.A. Decision support for collaborative marine spatial planning: identifying potential sites for tidal energy devices around the mull of Kintyre, Scotland deploying tidal devices around the Mull of Kintyre. Submitted to Regional Environmental Change.
- Janssen, R., Arciniegas, G.A., Verhoeven, J.T.A., 2012. Spatial evaluation of ecological qualities to support interactive land use planning. Environment and Planning B: Planning and Design. In press.

Technical reports, conference proceedings and articles in popular magazines:

- Alexander, K.A., Arciniegas, G.A., Janssen, R., Eikelboom, T., O'Higgins, T., 2011. Conflict Resolution (CORES) and demonstration "Planning for tidal devices around the Mull of Kintyre", Knowseas: Knowledge-based Sustainable Management for Europe's Seas, Deliverable D6.3, Scottish Association for Marine Science (SAMS), Scottish Marine Institute, Oban, Scotland, UK.
- Arciniegas, G.A., 2011. Planning for a polder in the Netherlands. Geodesign Project Integrates Water Management and Land-Use Planning", ArcNews, 33(1), ESRI, Spring 2011, 28-29.
- Arciniegas, G.A., Janssen, R., 2009. Using a touch table to support participatory land use planning. In B. Anderssen et al. (Eds), 18th IMACS World Congress - MODSIM09 International Congress on Modelling and Simulation, 13-17 July 2009, Cairns, Australia, 2206-2212. Modelling and Simulation Society of Australia and New Zealand Inc.: Canberra, Australia.
- Cornelisse, A.C., Janssen, R., Arciniegas, G.A, Omtzigt, A.Q.A., 2007. Verslag van de projectgroep workshop "Waarheen met het Veen" (Report of project group workshop "What to do with the peat?"), Vrije Universiteit Amsterdam, December 11th, 2007, Amsterdam. Institute for Environmental Studies. [in Dutch]
- Cornelisse, A.C., Janssen, R., Arciniegas, G.A., Omtzigt, A.Q.A., 2007. Workshop verslag "Waarheen met het Veen" (Workshop report "What to do with the peat?"), Province hall South Holland, October 26th, 2007, Amsterdam. Institute for Environmental Studies. [in Dutch]
- Janssen, R., Cornelisse, A.C., Arciniegas, G.A., Bubeck, P., Omtzigt, A.Q.A., 2008. Verslag onderhandelingsworkshop "Waarheen met het Veen" (Report of negotiation workshop "What to do with the peat?"), Vrije Universiteit, December 9th, 2008, Institute for Environmental Studies, Amsterdam. [in Dutch]

Chapter 2

Spatial evaluation of ecological qualities to support interactive land use planning

Abstract

Information on ecological qualities can play an important role in land use planning. This information is not always in a form that is suitable to support planning and negotiation among stakeholders. This paper describes an approach that uses ecological information based on expert knowledge in combination with spatial multicriteria analysis. Important elements of this approach are selection of evaluation criteria, assessment of scores, standardization, weighting and aggregation. The approach was tested as part of the land use planning process of the Bodegraven polder, a peat-meadow area in the Netherlands. An interactive mapping device (the 'Touch table') was used to support a series of interactive workshops with the various stakeholders to generate, assess and discuss land use plans for the Bodegraven polder. This paper shows how ecological information can be used to support decision-making.

Focus: this chapter describes a tool that combines GIS, MCA and a Touch table to support the evaluation of ecological qualities to facilitate ranking of spatial decision alternatives on the basis of ecology-related criteria. It demonstrates the use of the tool during a collaborative workshop where participants were asked to use the tool to evaluate and rank land use plans based on ecological qualities.

Research highlights:

- We combine information on expert knowledge with spatial MCA for evaluating land use plans.
- Stakeholders work together around the Touch table and transform this information into value maps to assess the qualities of a plan.
- Spatial MCA is used to combine value maps and generate scores that can be ranked.
- Value maps presented on the Touch table constitute a good platform for discussion between experts.

This chapter is based on: Janssen, R., Arciniegas, G.A., Verhoeven, J.T.A. Spatial evaluation of ecological qualities to support interactive land use planning. Environment and Planning B: Planning and Design. In press.

2.1. Introduction

The use of spatial decision support in land use planning can be viewed as a result of the integration of two types of research tools: Geographic Information Systems (GIS) and multicriteria decision analysis (MCDA) (Eastman et al., 1998; Janssen and Herwijnen, 1998; Feick and Hall, 2002; Malczewski, 2006). The integration of GIS and MCDA has led to the development of new integrated tools for spatial decision support and has also played an important role in the emergence of two major subfields of GIS science: Spatial Decision Support and Participatory GIS (Geertman and Stillwell, 2003; 2008). Participatory GIS typically involves map-based tools to support group work and collaborative tasks. Particularly, it focuses on the use of map-based tools to help stakeholders understand the spatial consequences of proposed land use alternatives, evaluate them and create new ones (Sieber, 2006; Jankowski, 2009, Carton and Thissen, 2009). Participatory GIS approaches can be used in face-to-face meetings on location but can also be internet-based.

Information on ecological qualities can play an important role in land use planning. This information is not always in a form that is suitable to support planning or negotiation among stakeholders. In this paper, an approach is described that is based on expert knowledge in combination with spatial multicriteria analysis and maps. The approach was tested on a land use planning process in the Netherlands. Within this process, an interactive mapping device called the ‘Touch table’ was used to support participatory workshops. The table was used in a series of stakeholder workshops to generate, assess and discuss land use plans for the area. Digital maps presented on the Touch table were the basis for communication among participants. This paper focuses on the role of ecological information in this process. Spatial multicriteria analysis was used to structure and aggregate ecological information. Important elements of this approach were selection of evaluation criteria, assessment of scores, standardization, weighting and aggregation. The application shows how ecological information was used to support decision-making and negotiation. This leads to the following two research questions:

- Can expert knowledge be used in a meaningful way to assess ecological qualities if no adequate models are available?
- How to develop a multicriteria-based approach to make this information suitable to support land use planning?

This chapter begins with a review of the major issues concerning the role of GIS and expert knowledge and participatory spatial decision-making. Next, a short description of the planning process is presented in Section 2.3. This section introduces the different types of stakeholder workshops, the Touch Table and the support it can provide in these workshops. The assessment of ecological qualities is described in Section 2.4 followed by aggregation in Section 2.5. Conclusions are presented in Section 2.6

2.2. Role of GIS and expert knowledge in participatory spatial planning

Geographic information science includes a number of research areas, each comprising different approaches to GIS. Among these, the ‘GIS and Society’ subarea addresses particularly the evolution of technology implementation in relation to the different societal contexts in which it has been implemented. According to the GIS and Society literature, these societal GIS implementations can be aggregated into one category called Participatory GIS (PGIS). PGIS deals with the effective use of GIS technology by groups in the context of collective planning and decisions (Balram and Dragicevic, 2006; Jankowski, 2009). Over the last six decades, PGIS has evolved along two major paths that relate to group decision-making, both of which focus on issues of human participation within spatial decision-making but with a clear distinction: Group Spatial Decision Support Systems (GSDSS) and Public Participation GIS (PPGIS) (Balram and Dragicevic, 2006).

GSDSS includes tools designed to support a group or different groups of users in addressing ill-defined spatial decision problems (Armstrong, 1994). A spatial decision problem is considered to be ill-defined or ill-structured if its objectives cannot be completely or precisely defined. PPGIS addresses the effective use of GIS technology by the general public and community groups in planning and decision-making for their communities, establishing different levels of involvement of the citizens and marginalized groups (Craig et al., 2002; Sieber, 2006). An important distinction between these two directions is that GSDSS focuses on systems and tools, whereas PPGIS gives more attention to the involvement of the public, their access to GIS and maps, and the incorporation of their preferences and relevant experience.

Recent implementations of GSDSS have been classified in the GIS and Society literature according to the specific goals of the system and the decision-making context. Relevant to this chapter are implementations referred to as Collaborative GIS, Planning Support Systems (PSS), and Geocollaboration approaches. Collaborative GIS integrates theories, tools and technologies of geographic information science with capabilities to support group decision-making (Balram and Dragicevic, 2006; Nyerges, et al., 2006; Jankowski, 2009). PSS focus on the incorporation of GIS and analytical models to support specific tasks of planning processes (Geertman and Stillwell, 2008). Geocollaboration, which falls into the emerging field of ‘geovisual analytics’, comprise recent approaches to integrate geographic visualization, analytical tools, human-computer interaction, and GIS to support spatial decision-making among multiple actors (MacEachren and Brewer, 2004; Andrienko et al., 2007).

A number of issues among the various PGIS implementations relates to the role of expert knowledge and judgment in spatial decision making. A first issue deals with the lack of a clear distinction between experts and locals (Sieber, 2006). Moreover, while cultures can vary in accepting expert knowledge, there can also be different levels of expertise among groups of stakeholders (Carver, 2003; Nyerges et al., 2006). More relevant to this study is the issue of linking local (qualitative, traditional) and expert (quantitative, scientific) knowledge (Craig et al., 2002; Jankowski, 2009). Representing and translating both local and expert knowledge and incorporating these knowledge sources into GIS and models to support spatial decision-making still remains a challenge for the GIS and Society literature (Beinat, 1997; Geneletti, 2005; Sieber, 2006).

The assessment and formalization of expert judgment can be an important step towards achieving informed decisions. Recent approaches to PGIS have been implemented to identify and integrate the expert knowledge and value judgments of decision-makers and stakeholders for spatial decision support. Recent literature has seen a number of approaches to integrate expert knowledge into decision processes for spatial decision-making. For some specific types of natural and semi-natural ecosystems, specific approaches for expert knowledge-driven evaluations have been developed. An example is the Functional Assessment Procedures (FAPs) for wetlands (Maltby et al., 2009). Spatially explicit expert knowledge can be communicated among different types of stakeholders through GIS-based visualization techniques. For example, 3-Dimensional modelling or visualization tools have been used to communicate expert knowledge as the output of simulation modelling during participatory planning workshops (e.g., Bacic et al., 2006) or to have stakeholders interactively generate land use scenarios using model based on expert knowledge (e.g., Bishop et al., 2009).

MCDA offers a range of more systematic methods to assess and compare decision alternatives on the basis of both local and expert knowledge (Malczewski, 2006). Aggregated and standardized indices and weighted suitability maps have been used to integrate expert knowledge in participatory processes of natural resource assessment (e.g., Lesslie et al., 2008; Store, 2009). Multicriteria methods constitute another means to measure and integrate both local and expert knowledge and have been implemented for mapping priority locations for sustainable land use planning (e.g., Strager and Rosenberger, 2006) or to map consensus between local stakeholders and outside experts for suitability mapping of future camp development (e.g., Chow and Sadler, 2010). Furthermore, multi-attribute value functions and fuzzy methods constitute additional methods to assess and formalize local or expert knowledge. Value functions (Beinat, 1997) have been used to mathematically represent expert judgment in order to assess standardized spatial indicators of landscape and ecological qualities (e.g., Geneletti, 2005 or Orsi et al., 2011). Fuzzy methods (Jian and Eastman, 2000), particularly membership functions, are alternative approaches to formalize local knowledge and expert opinions and to make this knowledge suitable for spatial evaluation among multiple decision objectives. Fuzzy methods have been used to integrate expert knowledge for site selection for solid waste (e.g., Ekmekçioğlu et al., 2010) or to assess sustainability of fishing developments (e.g. Chiou et al., 2005).

2.3. The planning process

This article describes an approach that uses ecological information based on expert knowledge in combination with spatial multicriteria analysis. This approach was tested as part of the planning process of the Bodegraven polder, a peat-meadow area in the Netherlands where water tables are controlled using pumping stations, sluices and weirs. The polder, which has an area of 4672 hectares, is located in the centre of the ‘Groene Hart’ (Green Heart), the largest national landscape of the Netherlands (Figure 2.1). The polder is part of a water-rich region with agriculture, nature conservation and recreation as primary activities. It consists predominantly of peat meadows, originating from peat lands drained in the thirteenth to fifteenth centuries and currently used for commercial dairy farming, but is also important for their high natural, cultural, and historical landscape values. Important current problems to be addressed in the polder are ground subsidence, steady disappearance of the peat-meadow landscape, inefficient water management, poor water quality, and the declining financial sustainability of dairy farming (Jansen et al., 2007; Querner et al., 2008; Woestenburg, 2009). Multiple stakeholders such as the local water board, the city of Bodegraven, the province of South Holland, farmer’s organizations and nature conservation organizations as well as individual farmers, residents and recreational visitors are involved.

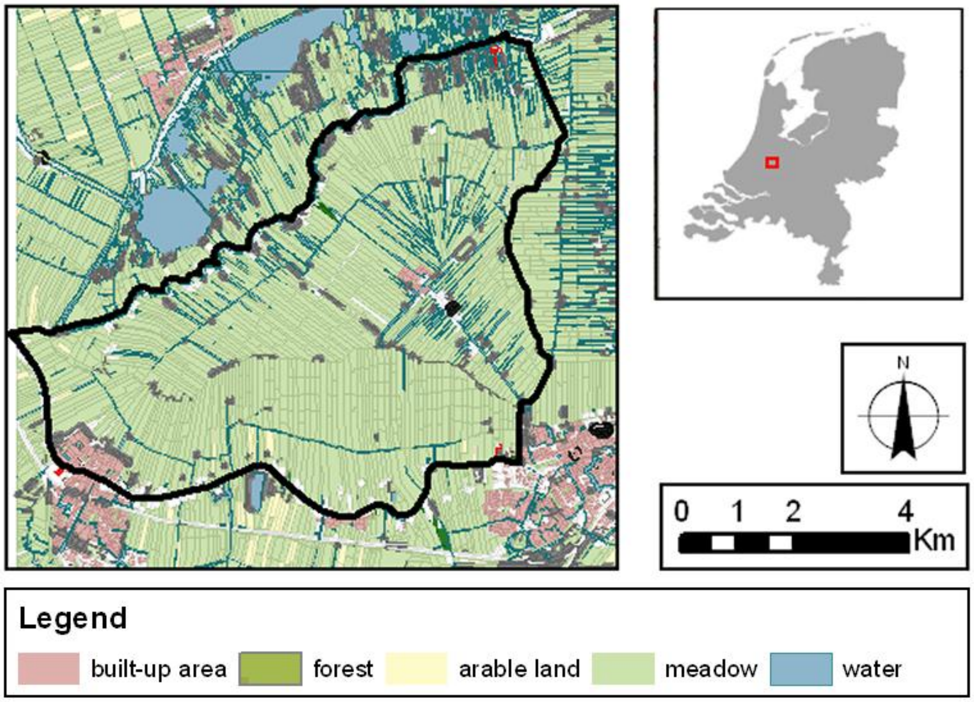


Figure 2.1. Map showing the location of the Bodegraven Polder, The Netherlands.

Land drainage in the polder causes soil subsidence, which increases the need for further drainage and so on. In the current practice (see Section 2.4.2), a lower level of the land is followed by a lowering of the water table which results in even more soil subsidence. At some point, this cycle has to stop because ground levels are sinking steadily further below sea level at an unprecedented rate and further lowering of water tables becomes too expensive or even impossible to sustain. Consequently, the provincial authorities have started a planning process to change both water management and land use in the area in cooperation with all stakeholders. Water management is the driving force within this process and land use has to adapt to changing water conditions (Strategiegroep Gouwe Wiericke, 2007). This implies that agreement is needed on both the water management strategy and the consequent land use.

The support of the planning process was structured in three interconnected workshops. The starting point was the design workshop where the terms of reference were defined. This involved the generation of a number of reference alternatives that covered the range of relevant solutions and an inventory of the objectives of the various stakeholders and the evaluation criteria linked to these objectives (Keeney, 1992; Belton and Stewart, 2002). Four objectives were identified: 1) profitability of agriculture; 2) minimization of land subsidence; 3) maximization of landscape quality; and 4) maximization of natural value. Three land use types were identified: intensive agriculture, extensive agriculture and nature. Participants of this workshop were ten representatives of public and institutional stakeholders including the water board, the city of Bodegraven, the province of South Holland, and nature conservation organizations. The second workshop focused on the assessment of the criterion and objective values of the different types of possible land uses in the area. Participants of this workshop were experts with different backgrounds and with local knowledge. This group of fifteen experts was recruited from two large research programs on peat-meadow management to cover all relevant aspects of the polder's problem. Information about the region was combined and presented as value maps to the experts to increase their understanding of the region. The value maps produced in the first two workshops were the input for the third workshop, the negotiation workshop. This last workshop supported the process of collectively changing a reference plan into a new negotiated plan. Participants of this workshop were fifteen members of the project group commissioned to develop a plan for the region.

The Touch table

The 'Touch table' (Figure 2.2) is a large (100 cm x 80 cm) touch-enabled screen that allows simultaneous input from a maximum of four users. Through conductive pads on which users can stand or sit, the table allows up to four users to work around it, recognizing which user is touching it and where. The table is a front-projected screen, which means it displays the image coming from an above video projector that is aimed down onto the touch surface. Both Touch table and video projector are connected to a laptop running ESRI ArcGIS® software. The projected image is matched with the touch display through a simple calibration process. Participants touch the table with their fingers to interact with the map in order to, for example, zoom in or out on an area, pan across an area, toggle map layers on and off, or changing weights or changing the land use of one or more parcels. Hardware includes a laptop, the Touch table and a separate screen. The table was developed at the Mitsubishi Electric Research Labs (MERL) (http://www.merl.com/) and is commercialized by Circle Twelve Inc. (http://www.circletwelve.com/). The application used for the workshops included tools based on multicriteria analysis for dynamic plan evaluation (see Sections 2.4-2.5), tools to support trade-off identification (see Chapter 3) and drawing tools to change land uses on the map. These tools were developed with CommunityViz Scenario 360 (http://www.communityviz.com/), a set of extensions for ArcGIS© specifically designed to support land use planning.

Figure 2.2. The Touch table.

Digital maps presented on the Touch table were the basis for communication among participants. The Touch table made it possible to visualize map-based information with, for instance, an historical map, an aerial picture or a soil type map as a background. The participants could draw on this background map and use their hands to change the land use patterns. After each change, the Touch table provided feedback on the effects of change on the quality of the plan for the various stakeholders.

2.4. Assessment of nature values

In the context of this study, ‘nature values ‘were defined as the ecological quality of the region, which in turn are defined by the relevant provincial and national policy documents. It is clear that the value of nature as seen by ecologists can be quite different from the value of nature from a human perspective. These values can be linked to the visual quality of natural value, recreational value, value for birdwatchers (Tyrvainen et al., 2007; Morgan-Davies and Waterhouse, 2010; Reed and Brown, 2003). In addition to nature, the study included agricultural, landscape and recreational value as objectives. In this context the value of birds to bird watchers and the value of the landscape for visitors were included as part of recreation.

Assessment of nature values using expert knowledge was part of the analysis workshop. Results of assessment were stored in a value table and presented in value maps. This section addresses the structure of the value table, the classification of parcels used, selection of evaluation criteria, definition of the value scale used for scoring and finally the use of expert knowledge to assign scores. Land use and groundwater level are the two elements that drive the valuation. The value for a parcel is calculated as the weighted sum of the values of all criteria within that parcel. Experts provide an assessment for the evaluation criteria for each for each land use/water level combination. The assessments are stored in the value table, which is used to assign a value to each parcel for each evaluation criterion.

2.4.1. Types of land use

Three types of land use, typical for peat-meadow areas, are identified: intensive agriculture, extensive agriculture and nature. Although agricultural use dates back to reclamation of the polders in the 12^{th} – 14^{th} centuries, current land use typically involves modern, commercial techniques to maximize meat and milk production. For this *intensive agriculture* land use, drainage keeps water levels relatively deep and fertilizer use is high. Pastures are grazed and/or mown up to eight times per year. Livestock graze in summer only or, in the most recent systems, remain in stables all year round. This form of land use leads to relatively high soil subsidence, high carbon dioxide production, high leaching of nitrates to surface waters and low potential for ‘meadow birds’ to breed.

Extensive agriculture is defined as a land use for commercial dairy production but supported by government subsidies to enhance natural values, in particular breeding opportunities for ‘meadow birds’. This may involve higher water tables, lower fertilizer use and/or measures to protect breeding ‘meadow birds’. *Nature* is a land use where meadow parcels are no longer in agricultural production but are used to maximize biodiversity values. Grazing by non-commercial livestock, mowing, and high water levels are examples of measures needed to achieve this (Vermeer and Joosten, 1992).

2.4.2. Characteristics of water management

Peat meadows in the Netherlands are typically located in polders that lie below sea level. Water levels, which can relate to either surface water or groundwater, are manipulated by pumping stations and are mostly geared towards agricultural land uses, with summer water tables either similar to or slightly higher than those in winter. Intensively used parcels often have water levels 60-80 cm below ground level in summer. Water levels within a polder may vary, being maintained in so-called ‘water level management units’ by the water board and even by individual land owners. Thus, a water management unit is a section of the polder in which only one water level is pursued and kept. In intensively used parcels, small pumps are often used to drain selected areas deeper than the normal ‘level section’. This has led to stronger subsidence in these parcels, resulting in polders with variable elevation. Currently, regional land use management aims to reduce the number of ‘water level management units’, to retard subsidence, and so to make the land use more sustainable.

2.4.3. Criteria for evaluating natural value

Depending on the history of land use and current management, three types of nature values can be recognized, that is ‘meadow birds’, ‘species-rich grasslands’ and ‘marsh birds’. Peat meadows managed to protect or support ‘meadow birds’ have a land use and water level management that maximizes the breeding success of bird species such as black-tailed godwit, (*Limosa limosa*), ruff (*Philomachus pugnax*) and lapwing (*Vanellus vanellus*), This involves relatively high water levels, less mowing or grazing and the use of nest protectors. Species-rich grasslands occur in areas without a history of heavy fertilizer use and with a relatively high water table. Marsh lands are low parts of peat-meadow polders which have become wetter because of a different water level regime. Such areas often have a history of intensive agricultural use, with subsidence causing low elevation. Water tables are typically at ground level or higher. The permanently wet character in combination with abundant nutrients gives rise to highly productive marsh flora, such as those dominated by reed (*Phragmites australis*) or rushes (*Juncus effusus*). Particularly the reed stands have high ecological quality because they form habitat for ‘marsh birds’ such as bitterns and reed warblers.

2.4.4. Selection of criteria

The three criteria for evaluating natural value, namely ‘meadow birds’, ‘species-rich grasslands’ and ‘marsh birds’, refer to the most important types of valuable nature in Dutch peat meadows (Vermeer and Joosten, 1992). ‘Meadow birds’ comprise bird species from open, farmed terrain. For the peat-meadow areas in The Netherlands, the most important meadow bird species are the black-tailed godwit (*Limosa limosa*), ruff (*Philomachus pugnax*), lapwing (*Vanellus vanellus*), redshank (*Tringa tetanus*), sky lark (*Alauda arvensis*) and meadow pipit (*Alauda arvensis)* (Teunissen et al., 2002). The Netherlands has an international responsibility for ‘meadow birds’, particularly the black-tailed godwit, because the peat meadows harbour the largest populations in the world. Most nature targets for reserves and extensive farming in these areas are related to maximizing conditions for ‘meadow birds’.

Species-rich grasslands are considered of high importance for nature conservation (Grootjans et al., 1996). These grasslands were common in the region until the 1950s because they were part of traditional agriculture but are now rare and include several red list species. Marshlands are important for their potential to provide habitat for ‘marsh birds’, notably the bearded reedling (*Panurus biarmicus*), great reed warbler (*Acrocephalus arundinaceus*), hen harrier (*Circus cyaneus*), bittern (*Botaurus stellaris*), night heron (*Nycticorax nycticorax*), purple heron (*Ardea purpurea*) and Savi’s warbler (*Locustella luscinioides*). A high water table has better opportunities nesting and feeding of these species. However, it also creates a risk of nutrient mobilization. Leaching of phosphates and nitrates into surface waters can be reduced by stimulating the growth of helophytes such as reeds or cattails.

2.4.5. Use of expert knowledge for scoring

Expert knowledge based on published information was used to fill the value table. For each criterion, experts were asked to assign a score to each land use/water level combination on a 0-10 scale (Table 2.1). Scores of 10 and 0 refer to the best and worst possible values for peat-meadow areas in the whole peat-meadow region of the western Netherlands. The scores for ‘species-rich grasslands’ were based on the work of Grootjans et al.(1996), who evaluated the botanical quality of mesotrophic and eutrophic species-rich grasslands in Dutch peat meadows on the basis of water level regimes and history of land use.

‘Meadow birds’ scores were based on Kleijn and Van Zuijlen (2004) who assessed their success subject to various land use and water level measures in the Dutch peat meadows. Information on the quality of restored marshlands on peat soil was derived from Schrautzer et al. (1996; 2006), who evaluated the results of a suite of restoration experiments in German peat meadows. In preparation for the workshop, experts were asked to use these sources to provide assessments for the three criteria and all land use/water level combinations. During the workshop, these assessments were fed back to all experts as value maps. The experts discussed the underlying map-based value scores and reached consensus on the set of score to be used (Table 2.1). Water levels in Table 2.1 range from open water (>0) to -100 cm divided in 10 cm intervals. The 0-10 scale used in the assessment matches the grading scale used in Dutch education, where it is assumed to have ratio properties within certain limits.

For the Bodegraven polder, only the criterion ‘marsh birds’ reaches the maximum value of 10 (see Table 2.1). ‘Meadow birds’ and ‘species-rich grasslands’ never score higher than 9 because the Bodegraven polder does not have any parcels where conditions are fully optimal. This is due to the land use history in the area. Table 2.1 shows that ‘marsh birds’ have the highest scores in the very wet areas where water tables are not lower than 10 cm below the ground. These conditions only exist when the land use is nature. As soon as the land is drained further, the scores quickly drop; scores of 0 are present only in the extensive and intensive agricultural land uses. Some combinations of water/level and land use cannot exist in practice.

The conditions for ‘meadow birds’ are optimal at a mean annual water table of 30-40 cm below the ground (Kleijn and Van Zuijlen, 2004). These conditions can be found in each of the three land use types. Values decline at both higher and lower water tables. The value is highest in the parcels of *nature* land use, where many measures to promote breeding ‘meadow birds’ are undertaken, for example, protection of nests from damage during mowing, delayed first mowing, application of low quantities of organic fertilizer. Next best is extensive agricultural use, where some of these measures are also applied. Intensive use has the lowest values, because breeding birds are disturbed by machinery or grazing livestock. ‘Species-rich grasslands’ have a distribution corresponding to areas with no previous history of heavy fertilizer use and no deep drainage. These species-rich plant communities thrive best at mean water tables between 20 and 50 cm below the ground (Grootjans et al., 1996; Schrautzer et al., 1996). Scores are relatively high where such water tables occur especially for land use ‘nature’.

Table 2.1. Value table for ‘meadow birds’, species-rich grasslands and ‘marsh birds’.

			Nature		
Land use	Water level		‘meadow birds’	‘species-rich grasslands’	‘marsh birds’
Nature		> 0	3	0	10
	0	-10	3	3	10
	-10	-20	5	7	5
	-20	-30	7	9	3
	-30	-40	9	9	2
	-40	-50	8	7	0
	-50	-60	5	6	0
	-60	-70	0	0	0
	-70	-80	0	0	0
	-80	-90	0	0	0
	-90	-100	0	0	0
Extensive		> 0	2	0	7
Agriculture	0	-10	2	2	7
	-10	-20	4	4	3
	-20	-30	6	5	0
	-30	-40	8	5	0
	-40	-50	7	5	0
	-50	-60	4	4	0
	-60	-70	3	0	0
	-70	-80	2	0	0
	-80	-90	0	0	0
	-90	-100	0	0	0
Intensive		> 0	1	0	5
Agriculture	0	-10	2	1	3
	-10	-20	2	1	1
	-20	-30	4	1	0
	-30	-40	6	2	0
	-40	-50	5	1	0
	-50	-60	3	0	0
	-60	-70	2	0	0
	-70	-80	2	0	0
	-80	-90	0	0	0
	-90	-100	0	0	0

It was assumed that the scoring is continuous within the whole range. This means that the difference in value between 5 and 6 is equal to the difference in value between 9 and 10. By assigning scores, the experts have implicitly defined three value functions (one for each type of land use) for each of the three criteria linking water levels to value measured on a 0-10 scale. An example of such a value function for 'species-rich grasslands' in *nature* land use is given in Figure 2.3. Note that this value function is continuous but not linear and ranges from 0-10 (Janssen, 2001). Table 2.1 does not provide information about the relative importance (the weights) of the three criteria. The weights are addressed in section 2.5.

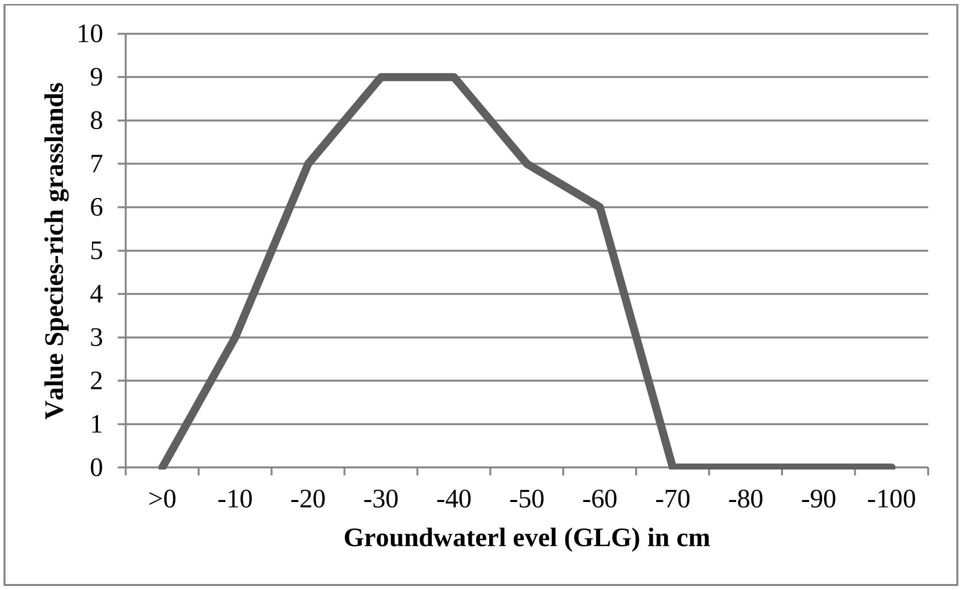


Figure 2.3. Value function linking groundwater level to the value of 'species-rich grasslands' for land use nature.

The value table was used to evaluate the current situation but also to evaluate future plans. As previously explained, two maps were needed for an effective evaluation: a map of the predicted groundwater levels and a land use map. At present, water management is inefficient with a large number of water management units each with their own water level. To make water management more efficient, three options to reduce the number of water level units were presented in one of the stakeholder workshops. The participants selected one of these options and decided to draw a new separation between two water management units during the workshop. This resulted in three water management units, as shown in Figure 2.4. In addition, the surface water level was set at -30 cm below the surface. Using these new parameters, ground water levels (GLG) were predicted for the year 2050 (Figure 2.4). Changing water levels creates the need to change land use. Areas where the groundwater level rises may no longer be suitable for agriculture and areas where the level declines may no longer be suitable for nature. A reference plan was developed to meet these new conditions (Stroeken, 2008, personal communication). This plan is shown in Figure 2.5 and involves development of new nature areas in combination with conservation of the traditional peat- meadow landscape.

Both land use and water level are now known for each parcel in the region. Together with the completed value table (Table 2.1), it is now possible to generate value maps for the three criteria: ‘meadow birds’ (Figure 2.6), ‘species-rich grasslands’ (Figure 2.7) and ‘marsh birds’ (Figure 2.8). Good conditions for ‘meadow birds’ occur in *extensive agriculture* or *nature* parcels with a water table 30-50 cm below the ground. This occurs in the parcels in the centre-north of the polder (Figure 2.6). The areas in the southern part of the polder are in intensive use and have water tables too low for ‘meadow birds’, whereas some nature parcels in the northeast are too wet (compare Figures 2.4, 2.5 and 2.6). The opportunities for ‘species-rich grasslands’ are best in nature areas in the centre-north part of the polder with water tables between 30 and 50 cm, moderate in extensively used parcels around these areas, and very bad in the drier, intensively used zones around the margin of the polder and in the southern half (Figures 2.4, 2.5 and 2.7). ‘Marsh birds’ only occur in nature areas with a very high water table, that is, a few parcels in the centre and some in the extreme northeast (compare Figures 2.4, 2.5 and 2.8). Two maps can be compared visually on the ‘Touch table’ using the ‘swipe’ function available in ArcGIS©. To do this, two maps were selected for comparison. Next, one map was made the background. The other map is put on top. By horizontally or vertically swiping over the map on top, the background map becomes alternately visible and invisible.

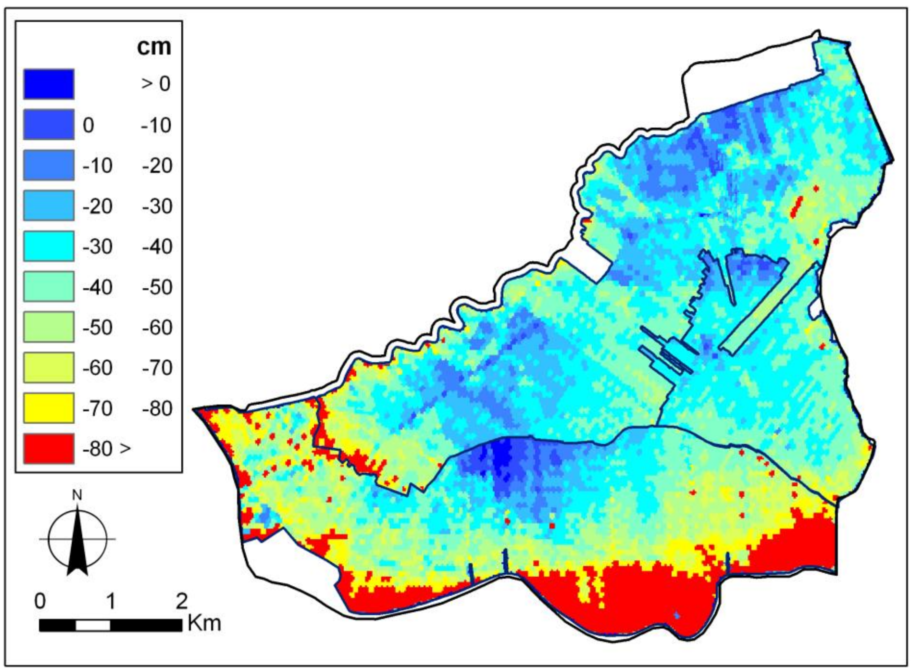


Figure 2.4. Average lowest groundwater levels (GLG) for the year 2050 (Jansen et al., 2007).

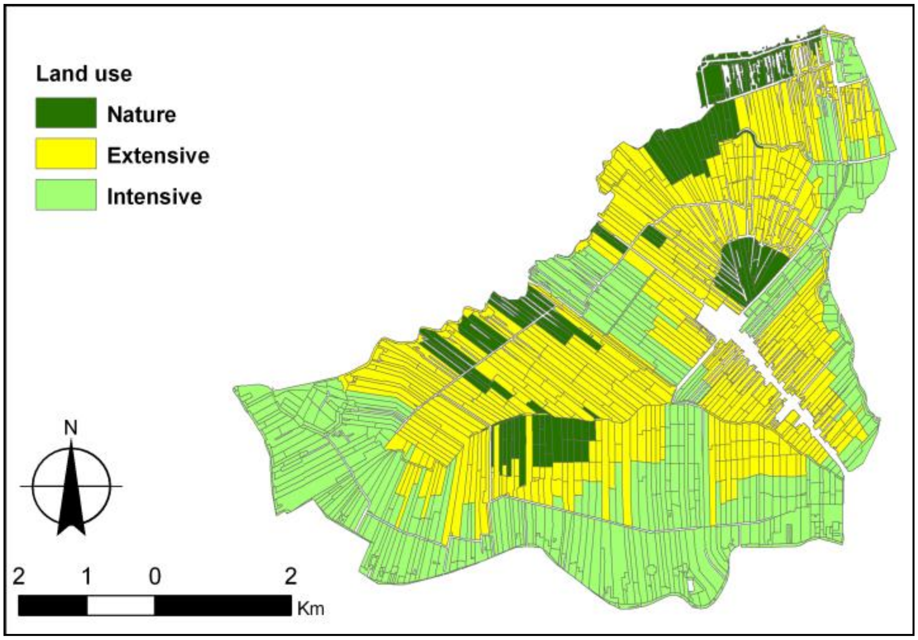


Figure 2.5. Reference land use plan.

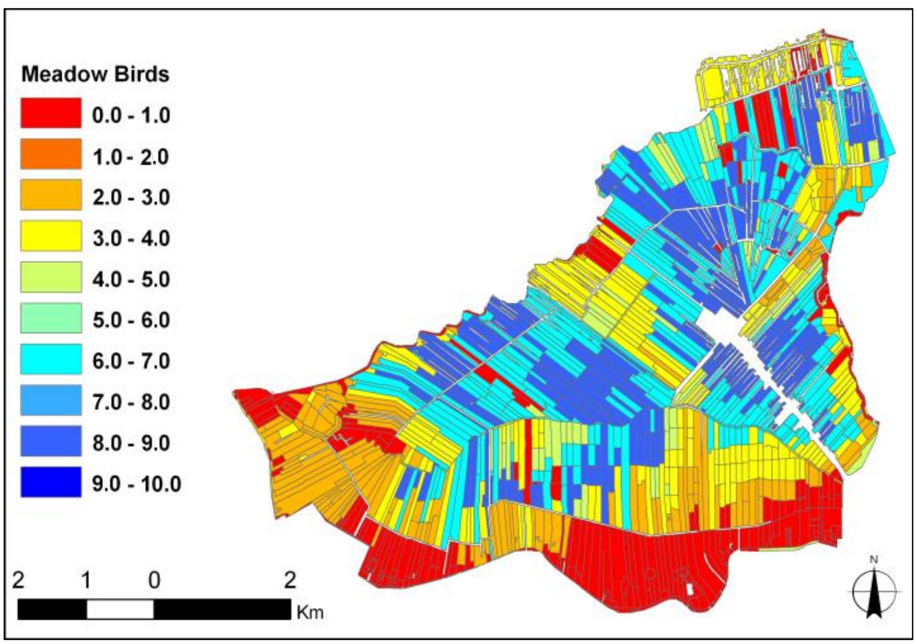


Figure 2.6. Value maps for 'meadow birds' (2050).

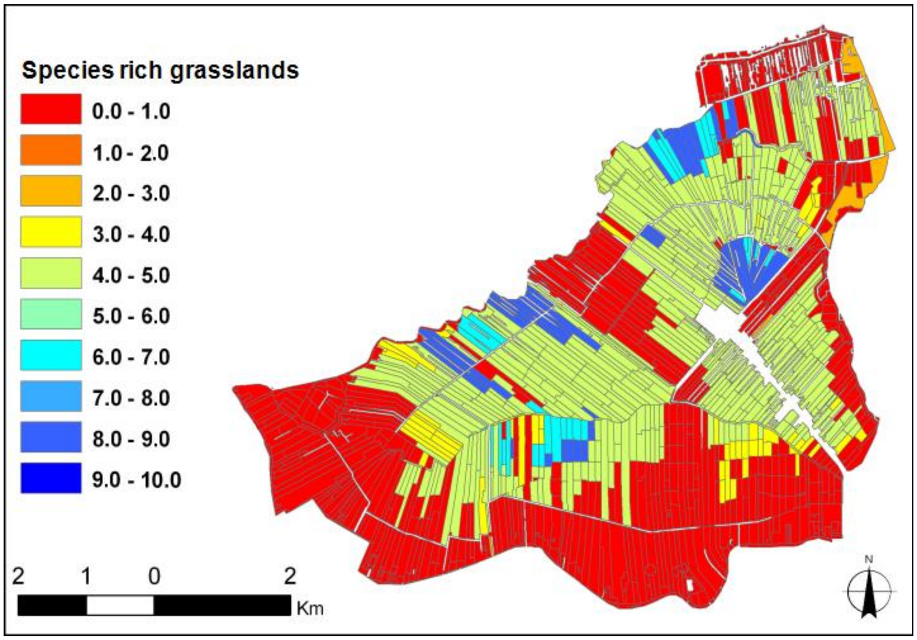


Figure 2.7. Value maps for 'species-rich' grass lands (2050).

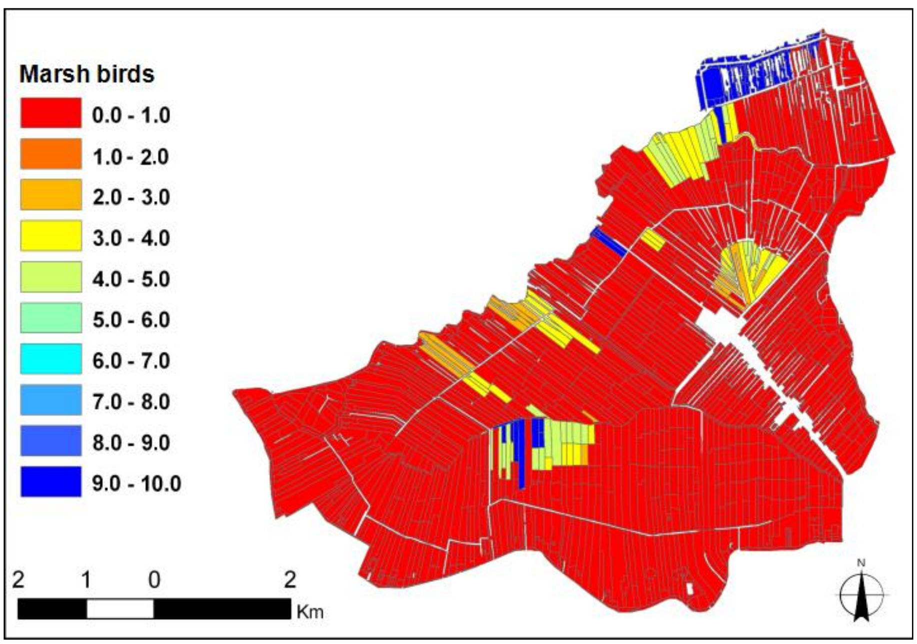


Figure 2.8. Value maps for 'marsh birds' (2050).

2.5. Aggregation: total nature value

Value maps were used to compare plans and to support negotiation about water management and land use. In practice, other criteria, such as economic criteria, needed to be included in the process in addition to nature criteria. Using value maps for all criteria would imply that the participants in the workshops need to take a large number of maps into consideration simultaneously. The need for decision support is based on the assumption that the information any decision maker can process is limited (see for example Miller, 1957 and Tufte, 1985). Previous research has tested this assumption on the use of spatial information for decision-making (Janssen and Uran 2003; Uran and Janssen 2003, Uran et al., 2005). The detailed information of the value maps easily exceeds this limit. It is therefore necessary to aggregate the individual value maps to a total value map. Aggregation of the criteria values to total nature value is performed in two steps: first the weighted sum of the criteria values is calculated; then the result is rescaled to maintain the 0-10 range of the scores. This section explains how aggregation is performed for the ecological quality objective. A similar approach is applied to the other three objectives.

2.5.1. Weights

To calculate the total nature value, it is necessary to combine the score information on the three criteria into one integrated score. The simplest way to do this is to calculate an arithmetic mean of the scores. However, this implies that the three criteria are equally important with respect to ecological quality. This would give a biased evaluation because ‘meadow birds’ are seen by nature conservation organizations, environmentalists and the general public as the most characteristic feature of peat-meadow nature. Some of the species (for example, the godwit) are rare in Europe but relatively abundant in the western Netherlands (Kleijn and Van Zuijlen, 2004). Taking this into account, the experts present in the analysis workshop decided to assign ‘meadow birds’ twice the weight (50%) of species-rich grasslands (25%) and ‘marsh birds’ (25%) (see Table 2.2).

Table 2.2. Value table for total nature.

Land use	Water level		Nature			Weighted sum	Total nature
			‘meadow birds’ (50%)	‘species-rich grasslands’ (25%)	‘marsh birds’ (25%)		
		> 0	3	0	10	4.00	5.71
Nature	0	-10	3	3	10	4.75	6.79
	-10	-20	5	7	5	5.50	7.86
	-20	-30	7	9	3	6.50	9.29
	-30	-40	9	9	2	7.00	10.00
	-40	-50	8	7	0	5.75	8.21
	-50	-60	5	6	0	4.00	5.71
	-60	-70	0	0	0	0.00	0.00
	-70	-80	0	0	0	0.00	0.00
	-80	-90	0	0	0	0.00	0.00
	-90	-100	0	0	0	0.00	0.00

2.5.2. Rescaling

The values of the individual criteria range from 0 to 10 with a value of 10 for the best performance in the region. However, the maximum of the weighted sum in Table 2.2 is not higher than 7 because the best conditions for one ecological criterion are necessarily less optimal for another. To illustrate, 'marsh birds' can only occur at very high water tables where 'meadow birds' cannot breed. While this could mean that total ecological quality is low in Bodegraven, this is not the case. To calculate the weighted sum it was implicitly assumed that the best parcel would have the score (10, 10, 10). Such a parcel cannot exist, as illustrated above. To make the total value consistent with the criteria values, the value of 10 must be linked to the best possible parcel in the region. Because of the high weight assigned to 'meadow birds', the best parcel is likely to score highly on this criterion. A parcel that scores 'meadow birds' 10, 'species-rich grasslands' 6 and 'marsh birds' 2 (10, 6, 2) proved to have the highest value possible for this region. This reference parcel is highlighted in Figure 2.9 (see in the north-east area of the polder's middle section, a parcel with its boundaries colored in black and its interior hatched). The weighted sum for this parcel is $0.50\times10 + 0.25\times6 + 0.25\times2 = 7$. The value of 7 for the best possible parcel is now rescaled to a value of 10 for total ecology. All other weighted sums are standardized similarly, resulting in the values for total ecological quality shown in the last column of Table 2.2 and the value map for 'Nature' presented in Figure 2.9.

The parcel with the highest possible scores can be seen as the 'reference parcel', against which all other parcels can be rated. To find the highest possible score, first all parcels with 'meadow bird' scores of 10 were selected, because this criterion has a double weight compared with the other two criteria in the combined evaluation. Excellent conditions (score 10) for 'meadow birds' imply water tables between 30 and 50 cm, which necessarily means adverse conditions for 'marsh birds' with its wet or even flooded conditions. This leads to scores for 'marsh birds' of 2 at maximum. At the same time, excellent conditions for 'meadow birds' require moderate applications of dung and lime. The highest possible species richness with rare species present in meadow vegetation requires oligotrophic, acidic conditions. Acidic conditions conflict with the addition of lime. Consequently the scores for 'species-rich grasslands' never surpass 6 where 'meadow birds' scores 10. This explains why the highest combined score for the three criteria together is 10-6-2.

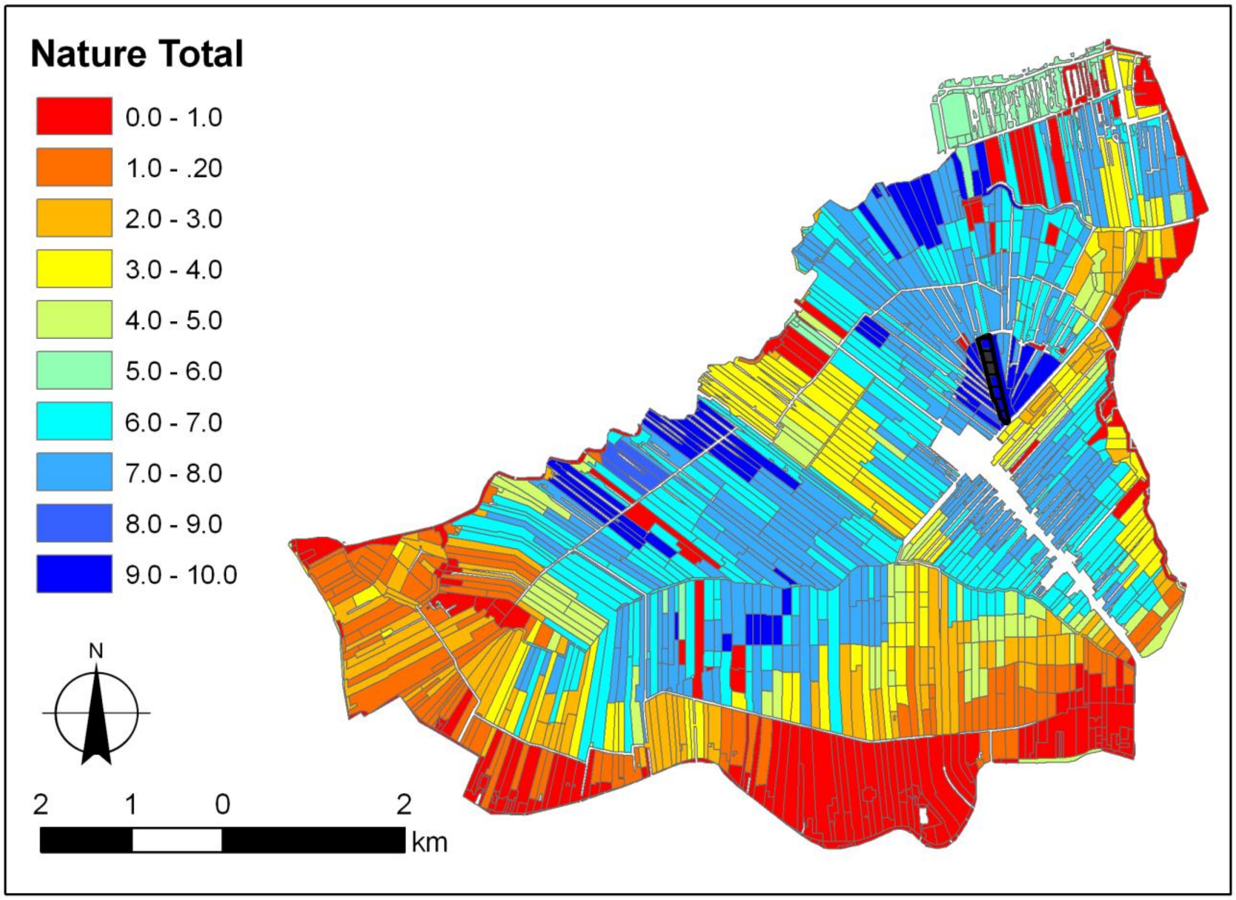


Figure 2.9. Value map total nature (2050). Boundary of reference parcel (north-east of middle section) is highlighted in black.

Figure 2.9 maps the total values for 'Nature'. It is clear that the highest nature values are in the north-west area of the polder. From comparison of this map with the land use map (Figure 2.5) and the ground water map (Figure 2.6), it can be concluded that the highest nature values are found in parcels with land use nature and water levels between 30 and 50 cm. Intermediate values are found with parcels with land use extensive agriculture and water levels in the same range. Very low nature values are found in the southern part of the polder and on the polder margins.

Figure 2.10 shows the aggregated values for the whole area for the individual nature criteria and total value. The value of each parcel is weighted with its relative area size and aggregated to calculate these scores. The total value was calculated with the same weights as the weights used in Figure 2.9. The red line above each criterion indicates the maximum possible value. For each criterion this maximum occurs for each parcel when the land use is selected with the highest value for that criterion. It is clear from the figure that this combination of land uses and water levels is already close to the best situation possible for 'meadow birds'. As this criterion was given the highest weight, this means that the current plan is quite good for ecological quality in general (see the last bar in Figure 2.10), despite the fact that, with different land uses, much better results could be achieved for 'species-rich grasslands' and 'marsh birds'. The situation is less good for 'species-rich grasslands', because there are not many areas with the necessary water tables and nature land use. For ‘marsh birds’ the aggregated value is also relatively low because some of the marsh areas have land use other than nature.

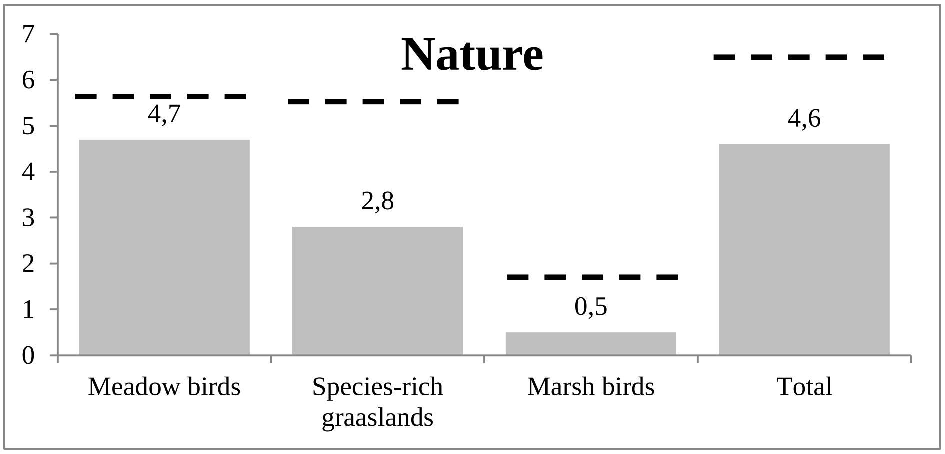


Figure 2.10. Aggregated values for ‘meadow birds’, species-rich grasslands, ‘marsh birds’ and total nature. Dashed lines indicate the maximum values under given ground water level conditions (2050).

2.5.3. Improving ecological quality

The value maps and aggregated values can be used to support negotiations for improving ecological quality. Figure 2.11 shows the value of all parcels if the whole region would be used for nature. This map is based on Table 2.1 and shows the best parcels for nature (blue), worst parcels for nature (red) and parcels in between. This map and similar maps for intensive and extensive agriculture form the basis for a negotiation support tool. The underlying idea of such a tool is to identify exchanges of parcels that increase the value of the total result (i.e., aggregated values) for all parties. This means that the participants representing nature would like to obtain parcels that a have a high ecological value and relinquish parcels with a low ecological value. Since high values for nature tend not to coincide with high values for agriculture, trades favourable for both parties exist. The design and implementation of the negotiation tools, which support the identification of such trades, are the subjects of the next Chapter.

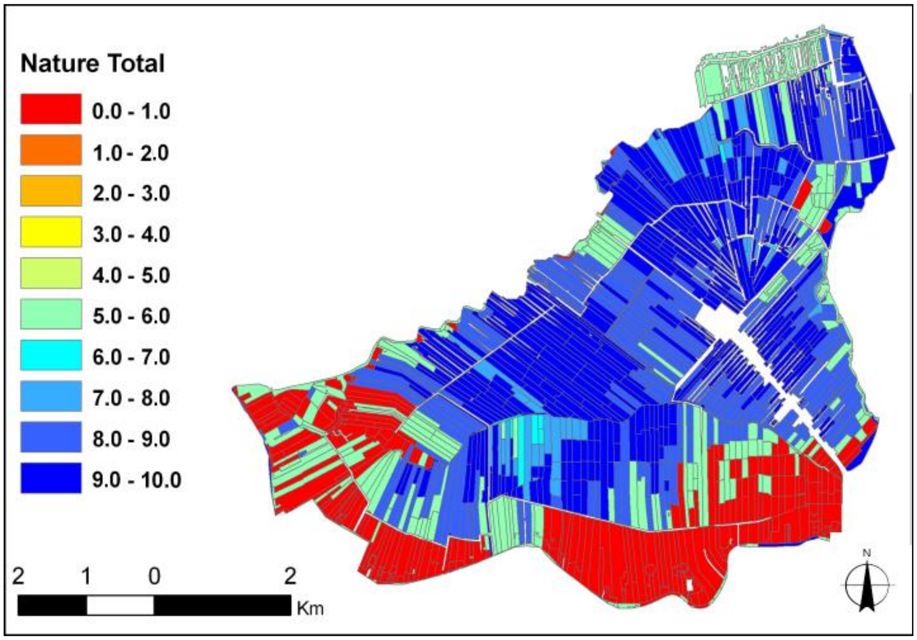


Figure 2.11. Total value nature if all land use is nature.

2.6. Conclusions

In this paper expert knowledge was combined with multicriteria analysis and maps to support interactive land use planning. In Section 1 two research questions were presented:

- Can expert knowledge be used in a meaningful way to assess ecological qualities if no adequate models are available?
- How to develop a multicriteria-based approach to make this information suitable to support land use planning?

2.6.1. Use of expert knowledge

Experts for the analysis workshop were recruited from two large research programs on peat-meadow management and were considered to cover all relevant aspects of the problem. Their expert knowledge was stored in a value table and presented in the analysis workshop in combination with a series of value maps. For all criteria, experts were asked to assign a score to each land use/water level combination on a 0-10 scale. The 0-10 score is equivalent to the grading system used in Dutch schools and proved easy to understand by the experts. Value maps proved to be a good platform for discussion between experts and were used to assess the scores in the value table. The value map for nature generated a discussion on weights and reference points which resulted in the rescaling presented in Section 2.5. Changes in the value maps also generated changes in the criterion values calculated for the area as a whole. This information, available on a separate screen, was not used by the experts. The experts used trial and error in alternating between value table and value maps. They reached consensus in a limited number of rounds. Assessment of the effects of alternatives is not always feasible because of time and money constraints. An advantage of the current approach is that the values were relatively easy to obtain. The experts judged that although the absolute values may not be always accurate, the results were sufficiently accurate to make relative judgements.

2.6.2. Use of multicriteria analysis

An important issue in the use of multicriteria analysis was the definition of the endpoints: what quality is linked to the value of 10 and 0. This was important both at the level of individual criteria and at the level of the total nature value. It proved possible to define clear reference points at both levels. The value map for nature triggered a discussion on the correct endpoints of the ranges used for evaluation. This discussion resulted in the rescaling discussed in Section 2.5.2. The total value for nature was extensively used in the negotiation tool. Experts used government policy as a reference to set the weights to calculate overall value for nature. As the politics behind these weights were clear, the weights were not questioned. Hence, the sensitivity of the value map for nature to changes in these weights was not tested during the workshop.

A limitation of this approach is that it assumes compensation between criteria. Losses on one criterion can be compensated by gains on another. The need for rescaling showed that this assumption is only valid to a limited extent. A second limitation is that the total value will be sensitive to changes in the weights. If no consensus on weights can be reached, this limits the usefulness of the approach. A third limitation is that, in the current application, the value of a parcel is not influenced by the value of neighbouring parcels. This ignores important spatial characteristics such as connectivity, homogeneity, or clustering. In the current application, it is left to the participants to include these aspects implicitly in their evaluation. Objectives linked to spatial patterns have been made operational in an earlier grid-based study (Janssen et al., 2008). It proved to be more difficult to do the same in a vector-based environment. Transforming the current vector-based application to a grid-based application with sufficient detail would make the application far too slow to be used in a workshop and also more difficult to use on the ‘Touch table’.

2.6.3. Use of the Touch table

Maps presented on the ‘Touch Table’ proved to be a good platform for discussion. Experts appreciated the possibilities to zoom in on specific locations and to inspect related maps. The possibility to make changes and evaluate the effects of these changes stimulated learning by doing. The flexibility of the Touch Table made it possible to integrate local and expert knowledge. The user friendliness of the approach made it possible to support both types of users sometimes even at the same time.

This chapter presented an approach that utilizes GIS, expert knowledge, multicriteria analysis and the Touch table to support the collaborative assessment of ecological qualities. In the next chapter, this approach is expanded to all possible land uses and complemented with capabilities for trade-off negotiation and land use allocation. Results from spatial multicriteria analysis are transformed into information on trade-offs, which is made explicit on the map to support the negotiated allocation of land use and optimization of land use quality. The approach is tested in a collaborative workshop.

Chapter 3

Map-based multicriteria analysis to support interactive land use allocation

Abstract

This article focuses on the use of map-based multicriteria analysis to develop a negotiation support tool for land use allocation. Spatial multicriteria analysis is used to make explicit trade-offs between objectives and to provide guidance and feedback on the land use changes negotiated by the participants. Digital maps are the means of communication among workshop participants and an interactive mapping device, or the Touch table, is used as the interface. Participants are informed about the relevant trade-offs on the map and use this information to change the land use maps. The approach is tested during a negotiation session as part of the land use planning process of the Bodegraven polder, a peat-meadow area in the Netherlands.

Focus: this chapter describes a tool that builds on the tool presented in the previous chapter. In addition to using GIS, MCA and the Touch table for the integrated evaluation of ecological qualities, the tool utilizes quality information on the range of all possible land uses to facilitate clarification of spatial trade-offs to support the negotiated assignation of land uses by stakeholders. The use of the tool is demonstrated during a collaborative workshop in which participants were asked to use the tool to improve the qualities of a land use plan while reaching a consensus plan.

Research highlights:

- We extend spatial MCA with capabilities for negotiation of trade-offs and land use allocation.
- Stakeholders use this information to negotiate land use changes and collectively optimize a land use plan on the Touch table.
- MCA scores effectively show the quantitative impacts of these changes.
- The tools help stakeholders develop a consensus land use plan that is perceived as fair by all stakeholders.

This chapter is based on: Arciniegas, G.A., Janssen, R., Omtzigt, N., 2011. Map-based multicriteria analysis to support interactive land use allocation. International Journal of Geographical Information Science, 25(12), 1931-1947.

3.1. Introduction

Multicriteria analysis (MCA) provides well-established decision support tools for policy analysis with conflicting objectives (Belton and Stewart, 2002; Janssen and Herwijnen, 2007). Conflicts can arise from the various objectives of a single decision-maker, but also from differences in objectives among various decision-makers. The aim of the methods may range from ranking of alternatives in order of attractiveness, clarifying conflict, to generating compromise solutions. Multicriteria methods can also be used if alternatives and/or objectives are spatial, as in spatial planning. This requires data on the geographical locations of alternatives, geo-referenced data on criterion values and, in many cases, a combination of multicriteria methods with a geographical information system (GIS). This combination is usually referred to as spatial decision support systems. GIS is used to produce thematic maps and to perform spatial operations. Multicriteria methods are used to translate these maps into value maps, optimal or compromise maps and rankings. Although multicriteria methods and spatial MCA are based on the same underlying concepts, addition of the spatial dimension leads to specific issues with regard to weights and standardization (Herwijnen and Janssen, 2002).

The most straightforward use of spatial MCA is comparison and ranking of alternatives. Spatial MCA can be used to link policy priorities to rankings but also to provide insight into the spatial distribution of the performance of the alternatives. Examples of GIS-MCA combinations can be found in Recatalá and Zinck (2008), Lesslie et al. (2008), Pelizaro et al. (2009), and Janssen et al. (2012). Spatial MCA methods can also be used to generate an optimal solution for a specific preference structure from a large or possibly infinite set of alternatives. In other words, the optimal solution is created or ‘designed’ using techniques based on tools such as multi-objective linear programming (e.g. Cova and Church, 2000, Aerts et al., 2003, Janssen et al., 2008, Ananda and Herath, 2008, Santé-Riveira et al., 2008). As a special case of design methods, interactive optimization offers solutions to the planner in a number of steps where, after each step, the planner can change the conditions for optimization (e.g. Stewart et al., 2004, Janssen et al., 2008). Using optimization to generate the optimal solution requires that all objectives can be described in mathematical terms and incorporated in the routine.

The tool presented in this paper builds on the use of spatial MCA for comparison and ranking. It uses results from MCA to support negotiations about land use change. The tool is interactive as it provides the negotiators with information on favourable exchanges of land use and provides feedback after each step. The MCA tool makes it possible to structure and aggregate the information in a way to make it suitable to support negotiation. Since it is interactive, it also leaves room for the negotiators to include considerations that were impossible to include in the formal specification of the problem. In developing the tool, special attention is given to the design of the maps used to support negotiation. In practice, effective use of maps is a difficult task for many people and the use of maps for evaluation is not a task most people are familiar with (Kraak and Ormeling, 2003; Andrienko et al., 2007; Carton and Thissen, 2009). The tool is applied within a land use planning process in the Netherlands. A large amount of information is available to support this process. Although relevant, there is too much information to be used in negotiation. Our multicriteria tool makes this information available in a format useful for negotiation. The interface allows for effective visualization of the MCA results.

This article focuses on the use of map-based MCA to develop a negotiation support tool for land use allocation. This article addresses the following research questions:

- Can map-based MCA be used to evaluate and communicate qualities of land use plans?
- Can map-based MCA be used to support negotiation on land use allocation?
- How do participants interact with the tool?

A short overview of existing tools is presented in Section 3.2. The use of map-based MCA to build a negotiation support tool is described in Section 3.3. The tool is demonstrated with a land use problem in the Netherlands in Section 3.4 and finally, conclusions on its usefulness are provided in Section 3.5.

3.2. Map-based MCA

Recent applications of spatial decision support for land use planning integrate elements of MCA and GIS. This integration has contributed to the further development of tools for participatory spatial decision-making (Eastman et al., 1998; Janssen and Herwijnen, 1998; Feick and Hall, 2002; Malczewski, 2006). However, the use of these tools in practice is not always successful (Uran and Janssen, 2003; Goosen et al., 2007). The output of map-based MCA can play an important role in participatory spatial decision-making but is not always easy to handle and present to different groups of stakeholders. Although often helpful for participatory planning, maps can also be a source of conflict (Carton and Thissen, 2009). MCA provides numerous methods to evaluate, compare, rank and present the performance of decision alternatives on the basis of several criteria and/or objectives. GIS is used to map and present the performance of alternatives. Examples of the use of map-based MCA for evaluation, comparison, ranking and mapping of decision alternatives can be found in Janssen et al. (2005), Pettit (2005), Sheppard and Meitner (2005), Goosen et al. (2007), Santé-Riveira et al. (2008) and Pelizaro et al. (2009).

Map-based MCA tools can also be interactive with user-friendly interfaces that allow users to provide input and generate output in real time. An example of an interactive MCA tool to support negotiated land use allocation is described in Goosen et al., (2007). Several studies recommend interfaces to integrate geographical visualization and MCA (e.g. MacEachren and Brewer, 2004, Andrienko et al., 2007, Bishop et al., 2009). An example is the interface developed by Bishop et al. (2009) to support forest management. The interface consists of a 3D display, that is, an aerial photography draped over an elevation model of the study area, navigation controls, and a number of interactive sliders with which users can set and change parameters. The interface was used by stakeholders to change criteria weights interactively during a planning session and to see the effects of these changes in the 3D display. The sliders allowed users to set criteria weights and also to set constraints on the criteria outcomes. As one user moved one particular slider, for example, environment, a weighted forest suitability map was generated and displayed as 3D objects representing trees overlaid on the 3D landscape. Other sliders moved accordingly, depending on the aggregated MCA output.

Land use plans can also be generated in a more automated manner using optimization methods. These include algorithms to find the best solution to a given spatial decision problem that has been formulated in terms of mathematical models (Malczewski, 1999). Common optimization methods are multi-objective programming algorithms, heuristic search/evolutionary/genetic algorithms and goal programming/reference point algorithms (Eastman et al., 1998; Malczewski, 2006). Examples of interactive MCA-based approaches that use optimization methods are the raster-based Rural Land-Use Exploration System (Santé-Riveira et al., 2008) and a raster-based approach to support design of land use plans as described in Janssen et al. (2008).

More relevant to this study are map-based MCA tools for collaborative spatial decision support. These tools combine MCA-GIS with visualization tools and multi-user interfaces (for example touch-enabled screens), which are often facilitated by mediators (e.g. Salter et al., 2009, Feick and Hall 2002). For example, Pettit (2005) examined the application of a collaborative GIS-MCA tool in a scenario-building exercise with local planners to support the formulation of a sustainable scenario for Hervey Bay, Australia. The tool, called What if?™, is based on three components: land suitability, growth-analysis model, and land-allocation model (Klosterman, 1999). Other studies recommend visual displays that link maps and MCA to support group-based decision-making. The CommonGIS tool (Andrienko and Andrienko, 2003; Andrienko et al., 2003) is a group-based spatial decision support system that links maps of decision options and dynamic statistical graphs that show MCA evaluation results. Voting techniques constitute other approaches for MCA-based collaborative decision-making (e.g., the Land-Use Planning Information System (Recatalá and Zinck, 2008) or the 'Spatial Group Choice' (Jankowski and Nyerges, 2001).

3.3. Map-based MCA for negotiation support

MCA is a tool to address decision problems with conflicting objectives. MCA can compare a set of alternatives using one or more criteria to determine the performance of each alternative for the given objectives (Belton and Stewart, 2002). When decision problems have a clear spatial component, an MCA method that incorporates this spatial aspect is needed: a spatial MCA. In a spatial multicriteria decision problem, the ranking of the alternatives is split into two steps: the aggregation of the spatial component and the aggregation of the criteria. These two steps can be carried out in different orders: first the aggregation of the criteria, then the aggregation of the spatial component, or vice versa (Herwijnen and Rietveld, 1999; Herwijnen and Janssen, 2002). The implementation of a spatial MCA as described in this article has the aggregation of the criteria as the first step and the spatial aggregation as the second step.

Spatial objects can be represented using a raster or vector data model. In a raster representation, all raster cells are ordered in rows and columns and share the same geometry. A vector representation differs from a raster representation in that a vector data set usually has diverse geometries. This has a consequence for the spatial aggregation, because different locations, lengths and or sizes have to be considered. When decisions are to be made on the level of spatial units with an explicit size and shape, such as parcels, watersheds or municipalities, a vector-based (polygon-based) decision support tool might be more appropriate than a raster-based tool. Furthermore, vector maps appear more realistic than raster maps, which can be an advantage for interactive tools (Janssen et al., 2008).

The capability of map-based MCA to identify trade-offs between objectives across spatial units can be used to incorporate MCA results in a tool that supports negotiations on land use changes. This section describes two polygon-based types of use of MCA results to support negotiation. The first type is implemented in the 'best & worst tool', which marks polygons (representing land parcels in our case study) that are very suitable or very unsuitable for each potential land use type based on their summed area. The second type is implemented in the ‘value trade-off tool’, which marks polygons that would profit from a change of land use based on their actual MCA value. With both tools, users can select and highlight polygons with MCA scores that are above or below user-specified thresholds. The use of the tools thus support the selection of *high-value* polygons as those polygons that have an MCA score above a certain threshold or *low-value* polygons if the polygons have an MCA score below a certain threshold.

In general, the criterion values for each polygon are dependent on the type of land use in combination with other attributes such as soil type and water level. The influence of the attributes on the value of a land use is dependent on the type of land use. For example, high water levels will generate a high value for marshland but a low value for agriculture. As value and land use are now linked, a change in land use will change the value of the polygon changes and ultimately the total value of the plan. The relation between value and land use is the basis for the negotiation routine. In this way the value of each polygon is made dynamic. Equation (3.1) shows the calculation of the spatially aggregated value s of objective j and for all m polygons in an alternative; r_{mj} is the MCA value of objective j for polygon m and standardized on the area of polygon m. This basic equation is used in both tools:

$$s_j = \sum_{m=1}^{M} r_{mj} \qquad (3.1)$$

The ‘best & worst tool’ defines the intersection T of the subset G with the highest and the subset B with the lowest MCA objective values. This intersection T contains the polygons that are potentially favorable for exchange. The polygon elements in subsets G and B are selected based on the sum of the polygon areas. The user defines two threshold area sizes for each land use type: the area of high-value polygons and the area of low-value polygons to be visualized. This means that there will be $2 \times U$ subsets, where U is the number of land use types. For each land use type l the area of suitable polygons is set by the users. This is threshold value i_{lg}. For each land use type l, a subset G_l with the high-value polygons will be selected from set P with all polygons. The set of polygons is defined as

$$P = \{p_1, p_2, \ldots, p_m\} \text{ for } m = 1, \ldots M \qquad (3.2)$$

Set D contains the same polygons as P, but ordered in descending order by their MCA objective score s_j (see Equation (3.1) for s):

$$D = \{d_1, d_2, \ldots, d_m \mid s_j(d_1) \geq s_j(d_2) \geq \ldots \geq s_j(d_m)\} \qquad (3.3)$$

Subset G contains Y elements from D, where the cumulative area of the polygons is smaller or equal to threshold i:

$$G_l(i) = \{d_1, d_2, \ldots, d_y \mid d \in D, s_j(d_1) \geq s_j(d_2) \geq \ldots \geq s_j(d_y) \wedge \textstyle\sum_{d=1}^{y} h_d \geq i\} \qquad (3.4)$$

The above procedure is repeated for the selection of the low-value polygons, then the subset D is substituted with subset A containing the polygons in ascending order by optimal MCA value. Threshold value i_{lb} is the number of hectares with the lowest scores for land use type l.

$$A = \{a_1, a_2, \ldots, a_m \mid s_j(a_1) \geq s_j(a_2) \geq \ldots \geq s_j(a_m)\} \tag{3.5}$$

The definition of subset B, containing the low-value polygons, is comparable with the definition of the high-value polygons:

$$B_l(i_{lb}) = \{a_1, a_2, \ldots, a_y \mid a \in A, s_j(a_1) \geq s_j(a_2) \geq \ldots \geq s_j(a_y) \wedge (\textstyle\sum_{a=1}^{y} h_a) \leq i\} \tag{3.6}$$

Figure 3.1a shows how the subsets G and B are visualized on a map. The 'value trade-off tool' selects subsets that visualize possible trade-offs between two objectives linked to two land use types: land use a and b. Threshold u_{ga} defines the minimum MCA value of a polygon for land use type a to be a high-value polygon for that specific land use type. All polygons that have an MCA value for land use type a that is higher or equal to the threshold u_{ga} are in subset G_a. The threshold u_{gb} defines the minimum MCA value of a polygon for land use type b to be in subset G_b. Subsets B_a and B_b contain the low-value polygons for land use a and b, respectively. In this tool, the sets do not need to be ordered before creating the subset. The sets G and B are defined as

$$G_j(u_g) = \{p \in P \mid s_j(p) \geq u_{gj}\} \qquad G \subseteq P \tag{3.7}$$

$$B_j(u_b) = \{p \in P \mid s_j(p) \leq u_{bj}\} \qquad G \subseteq P \tag{3.8}$$

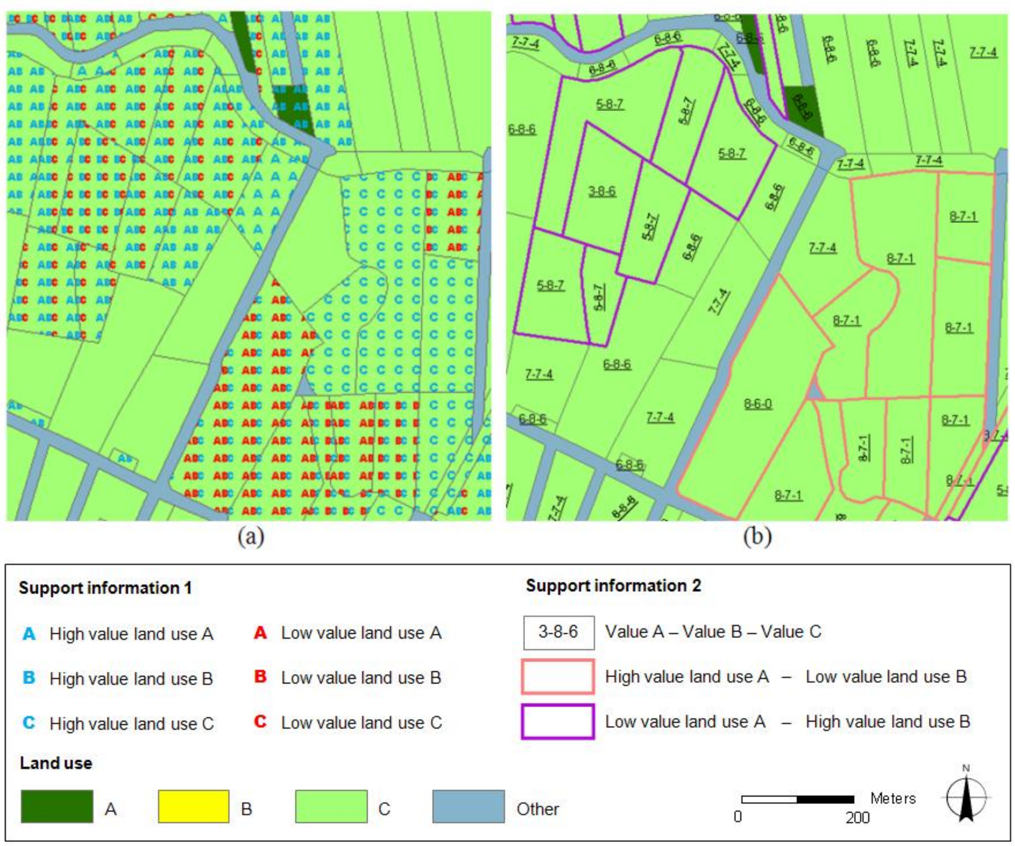


Figure 3.1. Results from two negotiation support tools: (a) the 'best & worst tool' and (b) the 'value trade-off tool'.

A trade-off set T is a subset of P representing polygons that are favorable for negotiation between a pair of land use types, such that high-value and low-value polygons for one land use type overlap low-value and high-value polygons, respectively, of a second land use. T thus contains polygons that are suitable for swap. A swap can be done between two land use types and is to be implemented on polygons within T. Let a and b be any two land use types from the set of L land use types. Hence $T \subseteq P$, $a \in L$, $b \in L$ and $a \neq b$.

Threshold i_l defines the number of elements of the sets with high-value and low-value polygons for the two land use types. For land use type a, the high-value polygons are in subset G_a and the low-value polygons are in subset B_a. For land use type b, the high-value polygons are in subset G_b and the low-value polygons are in subset B_b.

The overlap between high-value polygons for land use a and low-value polygons for land use b is defined as $G_a \cap B_b$. The overlap between high-value polygons for land use b and low-value polygons for land use a is the opposite case: $G_b \cap B_a$. Hence, the trade-off set (for land use a, land use b) is the union of both sets:

$$T_{ab} = (G_a \cap B_b) \cup (G_b \cap B_a) \tag{3.9}$$

In the 'best & worst tool', if more than two land uses are compared, the total set of polygons with trade-offs between all objectives is defined as

$$T = \bigcup_{\alpha=1}^{L} \bigcup_{\beta=\alpha+1}^{L} T_{\alpha\beta} \tag{3.10}$$

Where α and β constitute all possible combinations of elements from the set of land uses type L.

Figure 3.1a shows results from the 'best & worst tool'; the polygons in subsets G_l are marked with blue characters and subsets B_l are marked with red characters. Three land use types are compared, but it is also possible to compare four of five land use types. The number of land use types that can be compared using this method is limited in practice because it is difficult to read more than three symbols at the time. Figure 3.1b shows results from the 'value trade-off tool'; the colored polygon boundaries suggest possible exchanges between two land use types. Boundaries of the polygons that are potentially favorable for exchange are highlighted with a different color for each land use type. The purple boundaries indicate that these polygons have a high value for land use a and a low value for land use b ($G_a \cap B_b$). The pink boundaries show the polygons that have a low value for land use type a and high value for land use b ($G_b \cap B_a$). The numbers in the polygons show the value of that polygon for the possible land use types (three land use types in this example). The background color indicates the current land use of each polygon.

3.4. Negotiation support for the Bodegraven polder

3.4.1. The Bodegraven polder

The negotiation support tools were tested as part of the planning process of the Bodegraven polder, a peat-meadow area in the Netherlands where water tables are controlled. Chapter 2, Section 2.3 has provided a description of the Bodegraven polder, its current land use problems as well as the planning process started to address these problems. As part of the reallocation of land use in the polder, the provincial authorities devised long-term policies that aim to create 860 ha of nature and 1600 ha of land for extensive agriculture. This means that agricultural land must be purchased for conversion to nature and subsidies must be made available to support the transition to extensive agriculture (see Section 2.4.1 for a description of each land use type).

After consultation with the stakeholders, four objectives were identified: (1) profitability of intensive agriculture, (2) minimization of land subsidence, (3) maximization of the visual quality of the landscape, and (4) maximization of the natural value of the area. Each objective includes several criteria, such as 'meadow birds', 'species-rich grasslands' and 'marsh birds' for natural values. The score for each criterion is determined by both land use and water level. Three types of land use are identified: intensive agriculture, extensive agriculture and nature. Water level is divided into 10 levels in centimeters below ground level: (0, 0-10, 10-20, …, 80-90).

In preparation for the negotiation workshop, an analysis workshop was organized to assess each combination of land use and water level for all criteria and to set the criterion weights. Fifteen experts from a wide range of disciplines involved in peat-meadow research participated in this workshop. Together these experts covered all criteria included in the four objectives. Chapter 2 dealt in detail with the assessment of quality with regard to the fourth objective assessment 'maximization of the natural value of the area'. As a first step, value maps for all criteria were presented to the experts. Feedback from the experts was used to reassess the land use-water level combinations. Next, the criterion weights were used to generate aggregated value maps for each objective. These maps were fed back to the experts and corrections were made where necessary. A full report of the approach can be found in Janssen et al. (2012). Results of this workshop and the list of experts were presented during the introduction of the negotiation workshop. Both outcomes were considered to be sufficiently credible to be used in negotiation.

3.4.2. Negotiation support tool

The tools presented in section 3.3 constitute two different ways to support identification of polygons, which represent individual parcels, to be considered for change of land use (Figure 3.1). The 'best & worst tool' was selected for the polder Bodegraven because policy goals for this type of land use planning are usually set in terms of area size per land use. The participants enter these policy goals in hectares and the tool produces a negotiation map. On the basis of the area sizes specified for the three types of land use, the negotiation map (Figure 3.2) shows high-value (blue) and low-value (red) parcels for each of the three land uses: Nature (N), Extensive Agriculture (E) and Intensive Agriculture (I). For example, a sequence of characters 'N E I', colored respectively blue, blue and red, indicates that a parcel falls within the high-value area for Nature and Extensive agriculture and within the low-value area for Intensive agriculture. If these parcels are currently in use for intensive agriculture, they make good candidates for exchange. Parcels that are not within the specified limits do not show any ‘N E I’ information on them. The MCA results for the entire study area are plotted into a bar chart, which is presented on a separate display. Five bars appear in the chart, four of which represent the scores for four objectives and one the total score. If the participants change the land use of parcels as a result of the negotiations, the plan will be automatically reassessed in real time.

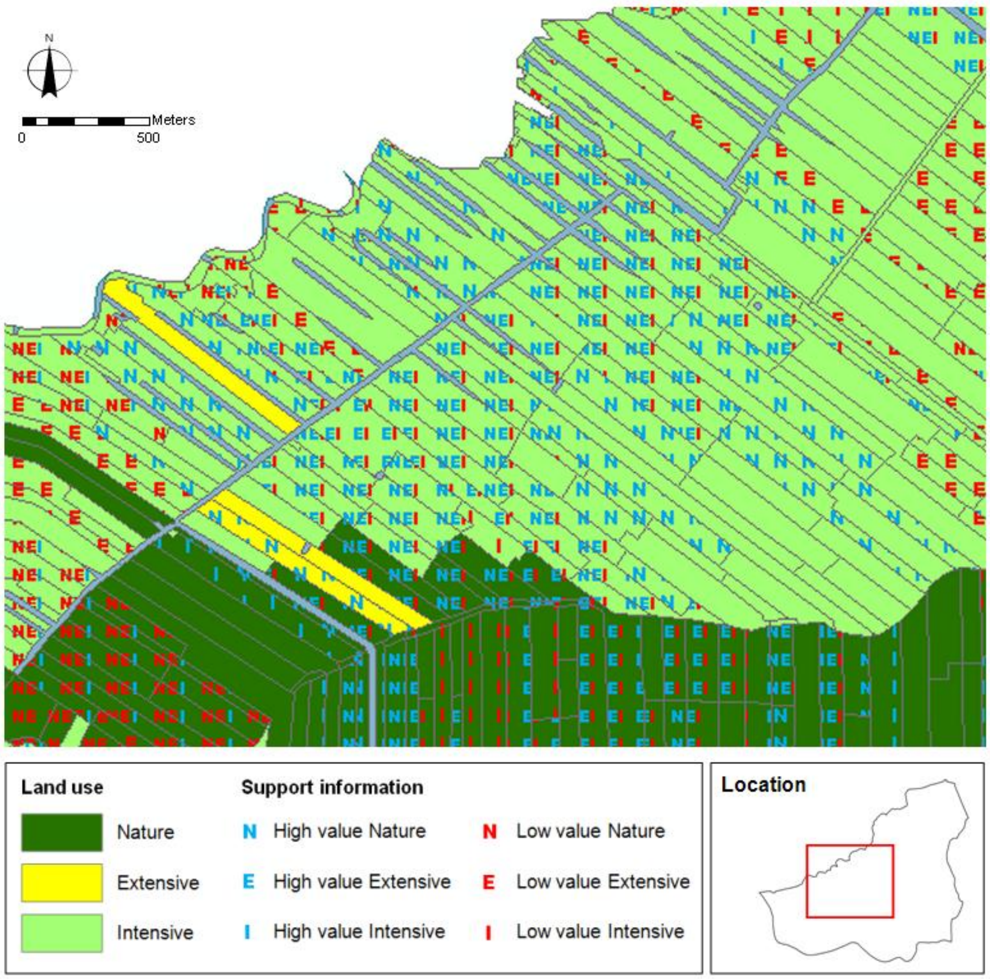


Figure 3.2. Negotiation Support on part of the land use map of Bodegraven. Map shows Nature (dark green), Intensive agriculture (light green) and Extensive agriculture (yellow). Blue and red letters indicate high (blue) and low (red) values for nature (N), Extensive agriculture (E) and Intensive Agriculture (I) of an individual parcel.

3.4.3. Setup of negotiation workshop

The process of achieving a consensus plan takes place during a face-to-face workshop. The half-day workshop consists of interactive sessions in which stakeholders are asked to collectively improve a reference plan with the help of negotiation support tools, which are linked to an interactive mapping device called the Touch table (see Chapter 2, Section 2.3, for technical details). Participants touch the table with their fingers to change the land use of one or more parcels. Figure 3.3 shows the workshop hardware setup, which includes a laptop, the Touch table and a separate screen. The software comprises MCA tools for dynamic plan evaluation, tools to support trade-off identification and drawing tools to change land uses on the map (Arciniegas and Janssen, 2009). The tools were developed with CommunityViz Scenario 360 (http://www.communityviz.com/, accessed April 2007).

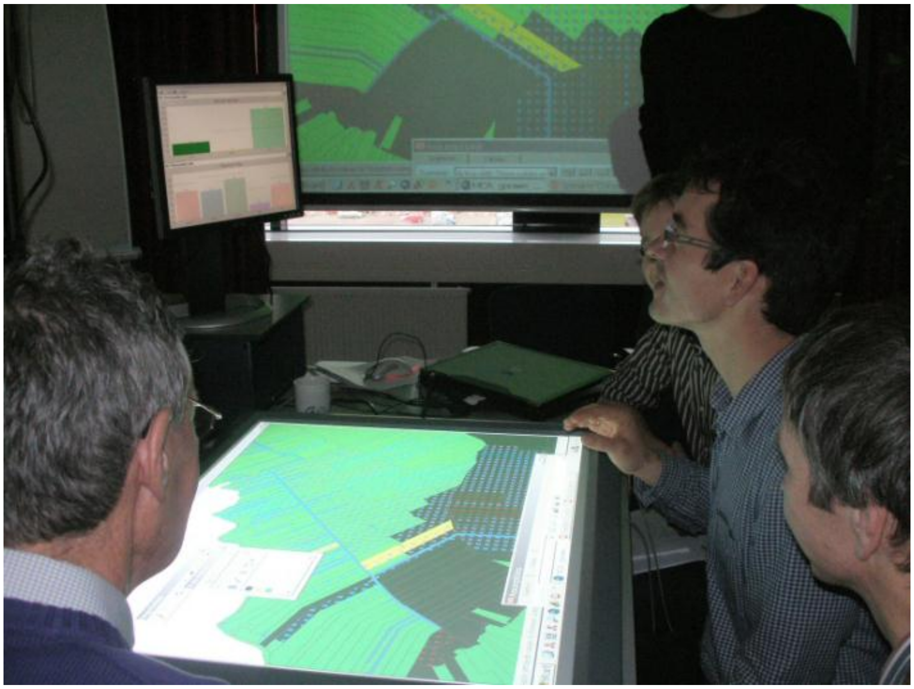


Figure 3.3. Workshop hardware setup: Touch table and separate screen with support information.

Nine steps are taken to generate consensus on a land use plan during a typical interactive session, as illustrated in Figure 3.4. (1) The session starts with a reference land use plan presented on the Touch table. (2) The participants select area sizes for high-value and/or low-value for one or more objectives. (3) The routine selects and highlights on the map those parcels that meet the selection conditions. (4) Feedback on trade suitability for one or all objectives is displayed on selected parcels on top of the land use map (Figure 3.2). This process is repeated until parcels potentially favorable for an exchange are identified. (5) With the feedback overlaid on parcels, the participants can focus on key spots across the polder and negotiate land use trades. (6) These exchanges are implemented by painting new land uses on parcels using the Touch table. The participants use their fingers to select a land use class and then allocate it to selected parcels. (7) As land uses of parcels are changed, a new land use plan is generated. (8) The qualities of this provisional plan are reassessed with MCA in real time. These results are presented as bar charts representing MCA scores and are available on the separate screen together with the number of exchanged hectares. It is possible to return to steps 2, 3, 4 and 5 to refine selection criteria during new rounds of negotiations. The process of specifying input, trading, reallocating and reassessing continues until the participants are satisfied with the new plan and its qualities. (9) This new consensus plan marks the end of the session.

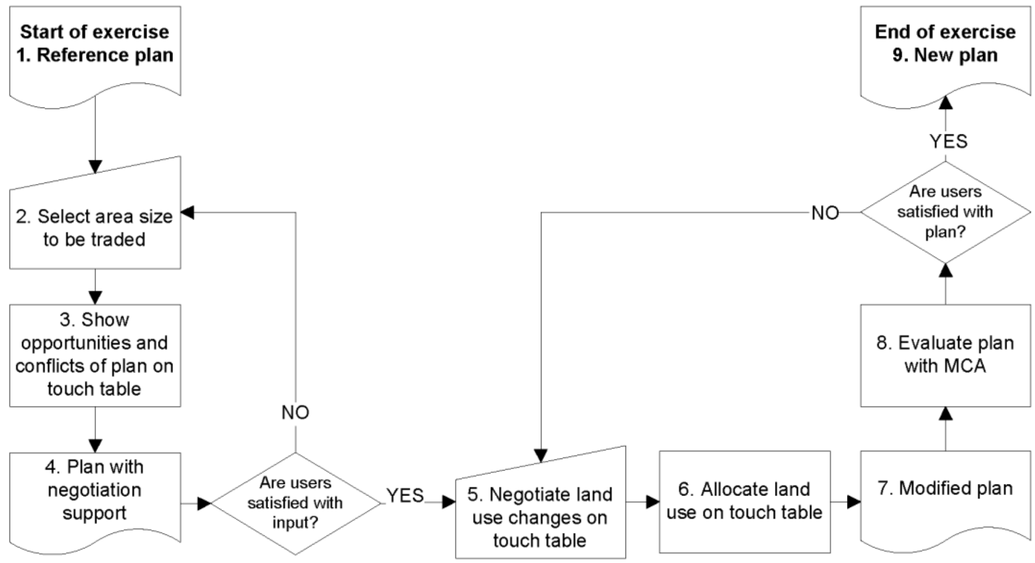


Figure 3.4. Flowchart of the process followed in an interactive session of a negotiation workshop.

3.4.4. Use of negotiation tool

A negotiation workshop was held as part of the planning process of the Polder Bodegraven. Participants of the workshop were experts involved in research about peat meadows in the region. The workshop included two parallel interactive sessions with two groups of participants working on two separate Touch tables. The purpose of the workshop was to assess the extent to which the tool can improve the qualities of a reference plan (see Figure 3.5). Both sessions were held simultaneously, for the same length of time and under the same conditions. In each session a group of three participants used the negotiation tools collectively to generate, within 90 minutes, a consensus land use plan that meets long-term provincial goals. Each participant was asked to play a stakeholder role from the three possible roles (farmers' organizations, agricultural nature organizations, nature organizations) and increase the quality of a specific objective (agriculture, landscape, nature, respectively). Both groups were asked to increase their individual objective and the total quality of the reference plan as they tried to achieve long-term provincial policy goals in hectares for each land use.

Long-term provincial policies aim to create 860 ha of nature and 1600 ha of extensive agriculture in the Bodegraven polder. The province of South Holland has already bought a substantial part of these 860 ha and plans to buy the remainder in the coming years. As a result of the change in water management, not all of the acquired land is in the right location. This means that agricultural land must be bought for conversion into nature and some land already bought can be sold back to agriculture (Strategiegroep Gouwe Wiericke, 2007). The assignment for the participants was as follows:

- Allocate 860 ha nature.
- Allocate 1600 ha of extensive agriculture and 1600 ha of intensive agriculture.
- Maximize the values of the four objectives and the total value.

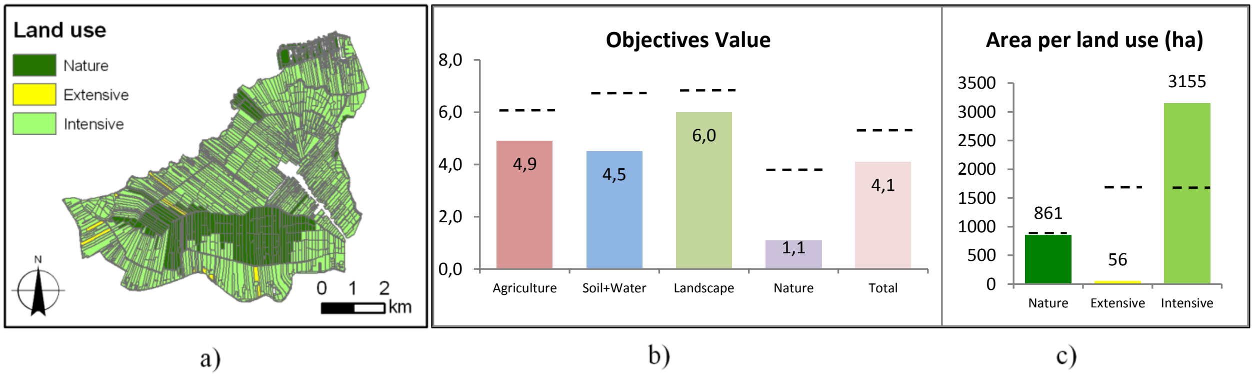


Figure 3.5. Start situation for the negotiation session: (a) start land use map; (b) aggregated objective values and total value of the start land use map; (c) area size per land use type. Dashed lines indicate the maximum values under the ground water level conditions in (b) and the policy goals set for the three land use types in (c).

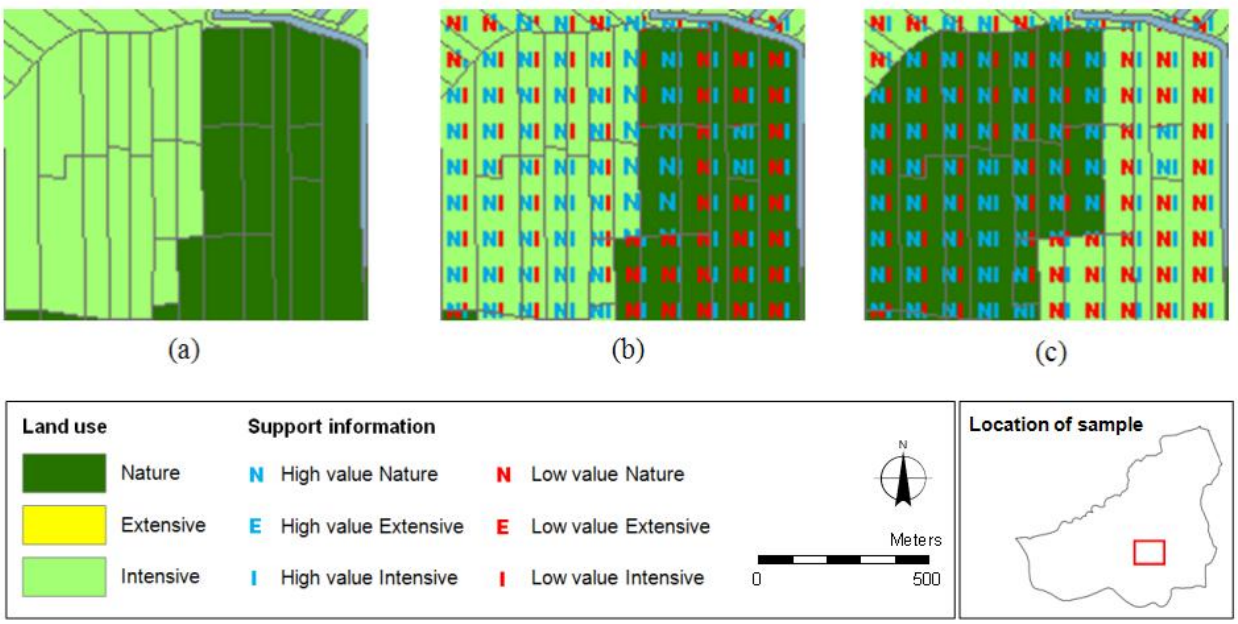


Figure 3.6. A land use exchange between Intensive agriculture and Nature: (a) a portion of the polder showing land uses Intensive agriculture and Nature allocated to parcels. (b) With the participant's input, support information is displayed on top of the parcels to facilitate the identification of potential trades. (c) This feedback on parcels is used to show participants those parcels whose land uses can be exchanged by painting a new land use.

Figure 3.6a zooms in on a part of Figure 3.5a, in which parcels are used for intensive agriculture and nature. The participant with an interest in nature uses the interface to retrieve only the best and worst 861 ha nature in the polder. A similar procedure is followed by a participant with an interest in intensive agriculture. With the input of both participants, feedback is displayed on parcels. Figure 3.6b shows blue N's and red I's overlaid on some parcels on the left currently used for intensive agriculture, indicating that these parcels are valuable for nature (blue N's) and not so for intensive agriculture (red I's). Likewise, some parcels on the right currently used for nature are valuable for intensive agriculture (as indicated by blue I's) and less valuable for nature (as indicated by red N's). These parcels are potentially suitable for an exchange that is favorable for both nature and agriculture. Both participants thus agree on the exchange and proceed to reallocate land use with the drawing tools on the Touch table. Figure 3.6c shows that nature has been reallocated to parcels with a high value for nature and low for agriculture; intensive agriculture is reallocated similarly. This exchange will likely increase the value for both nature and agriculture as well as the overall value.

3.4.5. Results of negotiations

Once the two sessions were completed, each group presented their consensus plan, which was followed by a discussion about their underlying ideas and the negotiation support provided. Figure 3.7 shows the two maps generated by the participants in each session and the qualities of both plans. The spatial distribution of land use on both plans differs quite significantly. By comparing the qualities of the two plans generated by both groups with those of the reference plan, it is clear that both groups succeeded in improving the land use situation for each evaluation objective and the total aggregated score (see Figure 3.8).

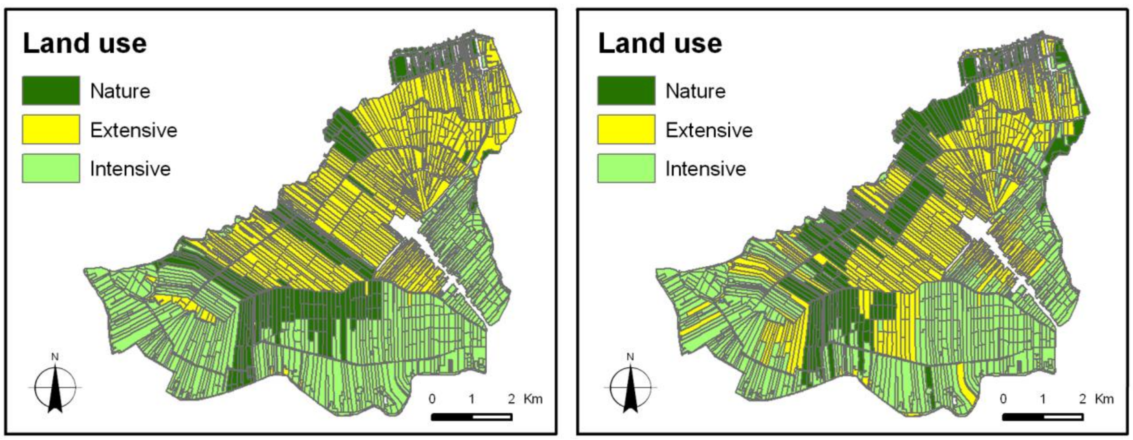


Figure 3.7. Land use plans developed simultaneously by two stakeholder groups during a negotiation workshop.

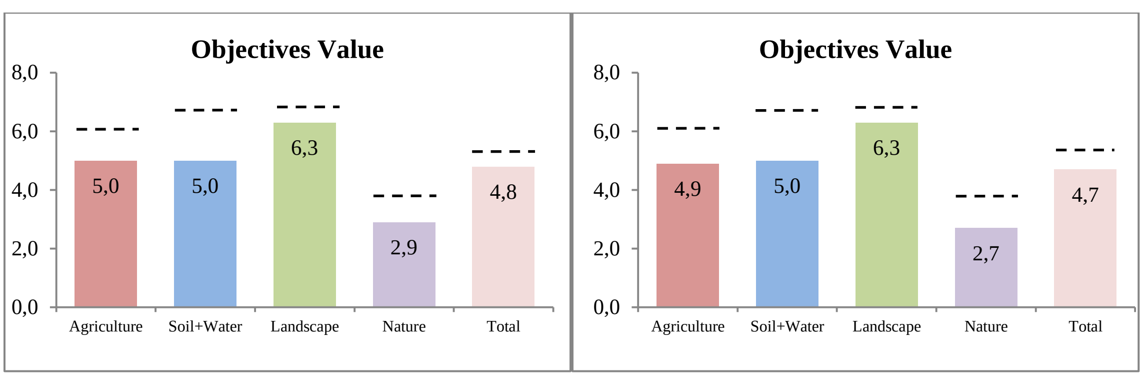


Figure 3.8. Objective and total values of the two land use plans. Dashed lines on each bar indicate the theoretical maximum value for each objective and total values.

Both groups found it difficult to reach the target of 1600 ha of extensive agriculture. Both groups improved the reference plan by similar percentages: the first group from 4.1 to 4.8 and the second from 4.1 to 4.7. Both groups were closely monitored during the sessions and parts of the process were video recorded. A feedback session at the end provided a qualitative impression of the approach and usefulness of the tools. To test approach and tools more systematically, the same exercise was repeated in 10 experimental sessions with three participants in each session (Chapter 4). Participants were recruited from the international M.Sc. program in environment and resource management of the VU University Amsterdam. The participants were asked to answer a number of survey questions related to their background and to the various tasks they had to perform. A full report of both the experiment and surveys can be found in the next chapter.

3.5. Conclusions

This article focused on the use of map-based MCA to develop a negotiation support tool for land use allocation. In Section 1 three research questions were posed:

- Can map-based MCA be used to evaluate and communicate qualities of land use plans?
- Can map-based MCA be used to support negotiation on land use allocation?
- How do participants interact with the tool?

3.5.1. Map-based MCA

The analysis presented in Section 3.4 begins with a number of maps that show the value of each parcel for 10 criteria on a 0-10 scale. All information on these maps is potentially relevant for supporting negotiation. MCA is used to structure and manage this information in a way that it can be used effectively by the negotiators. Participants used the separate screen with MCA results to discover how land use changes influenced the MCA scores. This required no further explanation. The only question asked was how the dotted line indicating the maximum value was calculated. Results from the survey revealed that 56% of the respondents considered the MCA scores to be useful or very useful and that 66 % considered these scores to be easy or very easy to use.

The definition of the criteria and setting of the weights were carried out in a special expert workshop (see Chapter 2, Sections 2.4.4 and 2.5.1). The results of this workshop and the list of experts were presented during the introduction of the negotiation workshop. Given the list of experts, the results were considered sufficiently credible to be used in negotiation. In addition to the aggregated information presented on the Touch table, underlying information, such as value maps for individual criteria and objectives, was presented as paper maps on the walls around the table. Video records of the session revealed that negotiators ignored the paper maps although participants agreed that the information was relevant for the negotiation.

3.5.2. Use of the interactive tool

Negotiators found the Touch table easy to use and sitting around the table allowed for learning by doing. Even users who do not really understand the underlying MCA get a feel for the implications of the method during the negotiation. After a short introduction, participants were able to perform the tasks without further support. Both groups continued the negotiations for 90 minutes without interruptions. At the start, participants experimented with the tool by changing land uses while observing the impact of these changes. In the negotiation process, the end result is reached in a large number of small steps that can all be reversed if needed. By observing the impact of each change, the participant gets a feel for the implications of the method. The survey showed that 62% of the test group considered the tasks to be easy or very easy to perform. Over 73% of all participants found the support provided to be useful or very useful. Positive aspects of the tool mentioned were as follows: learning by doing is stimulated; involvement is increased; and responsibility is better divided.

The negotiation tool requires input from the participants. The output provided combines the quantitative information stored in the tool with knowledge and ideas in the minds of the participants. If a model could be constructed that perfectly represents the knowledge and ideas of the participants, then this input could be replaced by an optimization model. Such a model could then generate the plan that theoretically has the highest value. In practice, developing such a perfect model is not possible. Some objectives are not explicit and only exist in the minds of the negotiators; others are impossible to translate into a formal model. In using the tool, participants are prompted to combine their ideas and knowledge with the information provided by the tool.

3.5.3. Results

It is important to frame the assignment in such a way that it is perceived as fair by the negotiators and allows room for give-and-take for all participants. In two test runs, the problem was framed as an allocation of 800 ha of new nature at the expense of existing agriculture. This automatically implied that the exercise had one winner and two losers. Participants in these test runs argued that the setting was unfair and were reluctant to cooperate. As a result, the problem was reframed as a reallocation of 800 ha of existing nature. As the allocation at the start of the negotiation was suboptimal, there was something to win for all negotiators. This proved to be important for the commitment of the negotiators to the process.

The participants were asked to maximize the objective values and total value. Looking at these values, both teams managed to reach almost the same increase in objective values and total value. However, the maps produced by both teams showed large differences. This was partly due to the differences in local knowledge between the groups. However, to a much greater extent it was due to the fact that not all objectives could be included in the formal model. More abstract objectives linked to the visual and cultural quality of the area proved difficult to make operational but definitely played a role in the minds of the negotiators. More work will be done to extend the current MCA model with more quantifiable definitions for such objectives. Fuzzy methods, specifically membership functions, could be an alternative to render these objectives operational (e.g. Ekmekçioğlu et al., 2010). These methods are argued to be adequate to deal with definitions that are linked to human perception and opinions (Bishop et al., 2009, Hajkowicz and Collins, 2007). Negotiators in both teams showed a cooperative attitude. They had the intention of doing a good job. The successful use of the tool depends very much on such a cooperative attitude. The experiments showed that the quality of the results was linked to the level of cooperation within the group. As such, it is very much a product of the Dutch way of decision-making. In situations of sharp conflict, or a more power-based style of decision-making, it is questionable whether the tool would be as useful.

This chapter has shown how to use multicriteria analysis in combination with GIS and the Touch table to support the collaborative optimization of land use plans through the use of information on trade-offs between objectives. The use of the tool was demonstrated during a negotiation workshop, which ends a series of three that includes design, analysis and negotiation workshops. The following chapter analyzes the effectiveness of the tools described in Chapters 2 and 3, namely tools for spatial evaluation and land use allocation. In an experiment with controlled conditions, two methods for measuring effectiveness empirically are compared, namely through user perceptions and through observations.

Chapter 4

Effectiveness of collaborative map-based decision support tools: results of an experiment

Abstract

This article reports on the results of an empirical analysis of the effectiveness of a set of collaborative spatial decision support tools developed to support a land use allocation problem in a peat-meadow polder in the Netherlands. The tools feature spatial multicriteria analysis as the means to make spatially explicit trade-offs between stakeholder objectives in three different ways: as colors on multiple printed maps, qualitatively on a single digital map and quantitatively on a single digital map. An interactive mapping device is used as the interface between spatial information and participants. A series of controlled experiments was conducted with 30 participants, who were asked to use the tools and perform specific individual and group allocation tasks. Data on the responses of the participants were collected through questionnaires, observer notes, video film and multicriteria scores. The analysis focused on three aspects of effectiveness: usefulness of the tools; clarity of tool information; and impact on decisions. The findings of this analysis are discussed within the context of the information offered by the tools, individual and collaborative work of participants and the spatial and numerical quality of the resulting land use plans. From the experiments, it is clear that the cognitive effort related to the volume and format of information is a critical issue in spatial decision support. This holds true for both the level of detail per item of information and the amount of information to be supplied to the participants. Although the quantitative tool provided the most information, the participants did not consider this tool the most useful and it did not produce the best results.

Focus: this chapter describes an empirical approach to analyze the effectiveness of collaborative map-based decision support tools, specifically the tools presented in Chapter 2 and 3, which integrate GIS, MCA, and the Touch table for supporting land use planning. The tools are tested with students during experimental sessions that replicated the workshop described in Chapter 3.

Research highlights:

- We conduct a series of controlled experiments to analyze the effectiveness of a set of spatial decision support tools.
- The experiments include tests of usefulness, clarity and decision-making impact of the tools.
- Effectiveness is assessed on the basis of user perceptions and performances both on an individual and a collective level.
- Best results are obtained with SDSS that provide users with information with a low level of complexity.

This chapter is based on: Arciniegas, G.A., Janssen, R., Rietveld, P., 2012. Effectiveness of collaborative decision support tools: results of an experiment. Environmental modelling & Software (2012), doi:10.1016/j.envsoft.2012.02.021.

4.1. Introduction

Developments in natural resource scarcity, climate change, urbanization and population growth lead to enormous challenges to policy makers at various spatial levels in the 21st century. A number of conditions are to be satisfied in order to address these challenges in appropriate ways. In particular, it is important that institutions are strong enough so that communities can cope adequately with the conflicts that arise because of the above developments and that are also inherent to policies to address them. Moreover, sufficient knowledge on these developments and their consequences is obviously needed. In the present article, the focus is on the knowledge theme, but it is important to link it to the institutional dimension because knowledge can improve competences of decision-making bodies.

Little explanation is needed that the developments indicated above are interrelated and that their effects on the positions of various parties take place via complex mechanisms, where various disciplines (ecology, economics, social sciences), time scales and spatial scales have to be linked. This calls for integrated modeling approaches (see for example Argent (2004) for a review). As Argent indicates, many models start as stand-alone initiatives of researchers in specific disciplines to address specific problems. However, the need for integration and wider applicability gradually leads to the development of models with a wider scope, both in terms of linkages with other models and domains of possible applications. These developments usually run parallel to efforts to make them more user-friendly so that model developers step back and users are more strongly involved (Liu et al., 2008). In order to make integrated models useful for real-world policy applications, specific elements are often added to provide bridges between the world of models and the world of policy arenas. Among these elements are multicriteria analysis (MCA) and geographical information systems (GIS). Multicriteria analysis is a decision support tool that contributes to a systematic comparison of policy alternatives in an integrated manner. An important element is that it explicitly addresses conflicting objectives from various policy domains, such as agricultural productivity, nature and landscape. GIS is important since many of the decision problems relate to land use and land cover. Integrated analysis of environmental problems calls for a systematic accounting of land use change addressing a complete set of land use types. In an equal manner, from a policy domain land use is often a key policy instrument. GIS is also very helpful in terms of visualization of policy problems and their solutions (Argent, 2004). The focus of this article is not on the development of integrated models as such, but on the fruitful ways of linking such models with real-world decision-making. This is done by using the tools of GIS and MCA in such a way that integrated models lead to knowledge that is presented in an integrated and intelligible way to policy makers working in a group context, implying some form of collaborative decision-making. More specifically, the article provides an in-depth test of the quality of various tools to convey the integrated knowledge generated by means of models to their users.

A common feature of collaborative map-based decision support tools is the use of maps as an interface between tools and end-users. These maps can be presented on paper as printed maps or on a screen, but are also increasingly being implemented in interactive mapping devices, such as the 'DiamondTouch Table' (http://www.circletwelve.com), the 'Maptable' (http://www.mapsup.nl), the multi-touch 'Microsoft Surface' (http://www.microsoft.com/surface), the SMART Board (http://www.smarttech.com), or interactive mobile devices such as GPS-enabled smart phones. Geertman and Stillwell (2009) distinguish between Planning Support Systems (PSS) and Spatial Decision Support Systems (SDSS).

They state that PSS generally pay particular attention to long-term problems and strategic issues while SDSS are generally designed to support shorter-term policy-making by individuals. They also state that SDSS deal primarily with operational decision-making while PSS focus more on strategic planning activities. Both PSS and SDSS combine tools from participatory geographic information systems (PGIS) with decision support tools, such as MCA and visualization tools (Eastman et al., 1998; Janssen and Herwijnen, 1998; Feick and Hall, 2002; Dragicevic and Balram, 2006; Malczewski, 2006). As explained above, MCA and GIS are promising tools to improve the effective use of output of integrated models since they potentially lead to integrated knowledge that is intelligible to the users.

Although many systems have been developed to date, the number of successful applications of both PSS and SDSS is still limited (Uran and Janssen, 2003; Geertman and Stillwell, 2009). In this light, it is surprising that the question of the effectiveness of these systems is seldom asked. Following the instrument approach of Goodhue (1995), two types of effectiveness can be distinguished:

1) How well the instruments enable users to carry out the intended tasks;
2) How well the instruments fit the capabilities and demands of intended users.

If the technology used in a system is relatively new, the Technology Acceptance Model (TAM) becomes relevant. Developed in the eighties by Davis (1989), the TAM model was originally designed to measure the factors that explain the acceptance and usage of classic information technology to the office environment, but has been since adapted to acceptance of wireless services and other types of information and communication technologies (ICT). This model predicts actual use of a device by its perceived usefulness and perceived ease of use. In this article, the focus is on the effectiveness of tools rather than to evaluate the technology. This article thus analyzes the effectiveness of a set of tools developed to support a land use allocation problem in a peat-meadow polder in the Netherlands. The tools were developed to support a series of planning workshops with governmental and non-governmental stakeholders. Results from these workshops, combined with observations and surveys, have shown that the tools are capable of supporting the planning tasks for which they were developed (see Arciniegas et al., 2011). Because the workshops were part of a political process, it was not possible to compare the situations with and without the tool or to compare different types of tools to support the same task. To facilitate drawing these comparisons and to test how well the instrument fits the capabilities and demands of intended users, a series of experiments was conducted.

In these experiments, three types of support tools were compared in ten sessions with a total of 30 participants, who were given specific individual and group tasks. The participants were observed while performing these tasks and answered survey questions after each task. This article describes the design and results of these experiments. The experiments focused on three specific aspects of tool effectiveness: 1) usefulness of the tool; 2) clarity of tool information; and 3) impact on decisions. Usefulness refers to the degree of success of a system in supporting a specific task or achieving a specific goal. Clarity refers to the ability of users to understand the information processed and presented by a tool. The impact of a tool on a decision process refers to the effects of the usage of a support tool on the decisions made by the intended users. This article is setup as follows: Section 4.2 includes a survey of literature dealing with the effectiveness of SDSS. The setup of the experiment is presented in Section 4.3. Results of the experiment are included in Sections 4.4 and 4.5. Conclusions are given in Section 4.6.

4.2. Assessing effectiveness of collaborative SDSS

This section reviews recent empirical studies that focused on measuring the effectiveness (or several aspects of effectiveness) of collaborative SDSS, based on integrated models. Although there is currently a wide range of applications of this type of tools, not all of them are successful (Vonk et al., 2005; Geertman and Stillwell, 2009). There are a number of studies that reported on the reasons behind the success or failure of these tools. These studies focused on SDSS for coastal zone and water management (Uran and Janssen, 2003; Van Kouwen et al., 2008); PSS for urban and regional planning (Pettit and Wyatt, 2009); and environmental decision support systems for environmental management (Poch et al., 2004). Results of these comparative studies recommended a closer link between tool developers and end-users during the development stages of the systems to ensure that the tool supports the intended decision problem. In addition, a number of studies have pointed out the importance of testing whether this type of SDSS are effective and used (e.g. Jankowski and Nyerges, 2001; Uran and Janssen, 2003; Goosen, et al., 2007; Vonk, et al., 2007).

Previous studies have discussed various aspects of the effectiveness of collaborative SDSS (e.g. Sheppard and Meitner, 2005; Nyerges et al., 2006; Salter et al., 2009; Schroth, et al., 2011). Effectiveness has been associated with the usability of a system in the context of human-computer interaction (Haklay and Tobón, 2003; Sidlar and Rinner, 2007; Meng and Malczewski, 2009). Moreover, effectiveness can relate to different aspects of a system or the tools included in it. From a broad perspective, three tool characteristics that are related to effectiveness of a tool can be identified: 1) the intended users of the tool; 2) the information included, processed and presented in the tool; and 3) the decision process to be supported by the tool and its outcomes. On the basis of these characteristics, this study distinguishes three individual aspects of effectiveness that can be evaluated separately, connecting each aspect to a specific question:

1) Usefulness: does the tool enable users to successfully perform the intended tasks?
2) Clarity: to what extent is the information presented in the tool understood by users?
3) Impact: how much do the tool and its outcomes influence the decisions made by users?

4.2.1. Usefulness of tools

Usefulness refers to the degree of success of a system in supporting a specific task or achieving a specific goal. Studies on usefulness generally involve sessions where participants are asked to interact with a tool to support the execution of tasks related to a certain spatial decision situation. Most of these studies deal with the degree of perceived usefulness, that is, the degree of satisfaction of users. Data on perceived usefulness can be collected by means of questionnaires or surveys (Dias, 2007; Voinov and Bousquet, 2010). For example, Hofstra et al. (2008) developed and tested an approach for collaborative decision-making that comprised mainly the usage of a multi-user touch-sensitive screen for disaster management in the Netherlands. This instrument allows simultaneous touches by multiple users and the use of maps, on which users carry out basic GIS tasks during the response phase after the occurrence of a disaster. This approach was tested in an experiment with 35 participants in order to assess its perceived usefulness and the perceived ease of use of the tool. Data were collected by means of a post-experiment questionnaire. The participants were asked to carry out a prepared assignment on a map of the city of Amsterdam.

Results of the experiment show the high potential of the tool for disaster management and its suitability for a broad group of users. As a second example, Haklay and Zafiri (2008) used screenshots of results achieved using a tool to measure its success. Further examples of empirical studies that aimed to measure the usefulness of tools can be found in Andrienko et al. (2003), Janssen and Uran (2003), Goosen et al. (2007), Sidlar and Rinner (2007) and Inman et al. (2011).

In an empirical study, Sidlar and Rinner (2009) assessed the success of a map-based online geo-collaboration tool. The authors measured how well the tool facilitated an online geographically referenced discussion. The tool consisted of a web-based mapping application, with which users can provide feedback on land use plans by pointing to places on a map in combination with an on online discussion forum. An experiment was conducted with 11 participants. The degree of success of the tool was calculated as a 'utility ratio', which is the ratio of the actual use of the tool (counts obtained from web server log files) over the potential use (number of geographically referenced contributions made to the discussion forum). The success of a tool can also be measured by tracking user-computer interaction. For example, Meng and Malczewski (2009) demonstrated how to quantitatively evaluate the usability of a web-based public participatory GIS called 'ArgooMap'. ArgooMap comprised an MCA module to calculate the scores of all alternatives and a 'Group Decision Component', with which alternatives are ranked based on the majority's preferences. The experimental part of this study examined the relationships between user characteristics and system usability. In this study, usability was regarded as the easiness of using these systems for a wide range of users and was defined in terms of the users' performance, which involved effectiveness, learnability, efficiency and user satisfaction after interacting with the tool. Tourists and local residents were invited to use the tool and asked to identify preferences regarding the location of new parking places. Post-questionnaires and a tool called 'UsaProxy' were used to collect data in order to test the usefulness of the tool. UsaProxy tracks and records all interactions between the user and the tool remotely. Data were analyzed with descriptive statistics and by correlating user characteristics and success metrics. Boroushaki and Malczewski (2010) used a quantitative measuring of the degree of consensus achieved by participants as an indicator of the effectiveness of an online collaborative tool.

The usefulness of a tool can also relate to both its functionality and usability. For example, a recent study by Vonk and Ligtenberg (2010) included the evaluation of two PSS for sketch planning. The authors defined functionality as the match between the planning tasks and the system. Usability was defined as the match between user needs and the PSS. The goal of this evaluation was to compare traditional PSS development methods that involved only PSS developers with an approach that involved a close collaboration between direct users and PSS developers. Both PSS integrate drawing and sketching with basic GIS and a tabletop called the 'Maptable' (http://www.mapsup.nl). Their evaluation comprised aspects, such as functionality, usability and the relative advantage between traditional methods and a socio-technical development approach. Eight expert observers filled out an evaluation form with questions and criteria. Both the planning and evaluation processes were filmed. Data were obtained from observations and the comments of the experts. Results from the evaluation suggested that cooperation between users and programmers of PSS during development stages contributes to an increased functionality and usability. Vonk and Ligtenberg (2010) recommended further testing these systems, particularly those featuring tabletop technology, for usability for various types of planning tasks, processes and user groups. Pettit et al. (2011) assessed strengths and weaknesses of landscape visualization tools, namely virtual globes, for communicating alternative landscape scenarios in collaborative environmental planning. A number of alternative landscape scenarios were communicated to two types of audiences: current users (12 environmental managers and planners) and future users (89 undergraduate spatial information students). Interviews and web-based surveys were used on each audience respectively to assess the tools and to derive suggestions for tool improvement.

4.2.2. Clarity of information

Clarity refers the ability of users to understand the information provided by a tool. It does not necessarily relate to the design of the tool or the models used to generate the information. As an example, Janssen and Uran (2003) used interviews to analyze how well stakeholders understood the results of an SDSS for water management in the Netherlands. The stakeholders were interviewed to determine their preference for maps, text, or graphs as a means of communication and to analyze the relationships between level of detail, perceived confidence, difficulty, correctness and the perceived value of maps for decision-making. An interesting result was that although participants indicated that they preferred fairly detailed maps, this did not always coincide with their ability to use these maps. Goosen et al. (2007) analyzed the use of a negotiation support tool for regional water management in the Netherlands. Information presented included valuation tables, value maps, conflict maps and the performance score for each objective calculated with MCA. The participants worked in three parallel groups and were asked to represent different stakeholder interests of a wetland area in the Netherlands. After each workshop, the participants filled out a questionnaire on their understanding of the tool and the information involved. Results from these surveys showed that the participants found the value maps easier to understand than the aggregated value scores.

Kennedy and Bishop (2008) reported on six experiments that aimed to measure participants' land use knowledge and choice behavior when using a virtual decision-making environment. A virtual environment integrates 3D visualization and results from MCA to assess relative impacts of different land use scenarios. Twenty-nine people participated in the experiment and were asked to play the role of a farmer and manage three parcels of land for the next twenty-five years. They were then asked to make land use choices under six different experimental modes. The modes differed in type of information presented (2D and 3D) and decision conditions (in isolation and seeing neighbor's parcels). After the sessions, the users were asked to fill out questionnaires in order to rate their experience and knowledge. Results were of limited statistical significance as to what extent knowledge of choices of participants using the virtual environment influences land use choice behavior. Consequently, further testing with refined controlled conditions was recommended. Several other empirical studies stressed the importance of clarity of a decision support tool (Andrienko et al., 2003; Bacic et al., 2006; Sidlar and Rinner, 2007; Pettit et al., 2011). Particularly, Andrienko et al. (2003) discussed the importance of promoting a clear understanding of how the results are obtained and the existence of different styles of decision-making that require distinct support tools. Similarly, Bacic et al. (2006) stressed the relevance of the role of visualization to increase the stakeholder's understanding of a decision problem.

4.2.3. Impact on decision process

The impact of a tool on a decision process refers to the effect the use of a support tool has on the decisions made. The effect can be positive, negative, or absent. The use of a tool can also influence decisions to varying degrees. Impact can be reflected on the results achieved by users, or can be related to the extent, frequency, and so on, of information use that lead to decisions. There are several approaches in the literature that utilized different indicators to measure the impact of SDSS. Nyerges et al. (2006) tested a collaborative SDSS for ground water and surface water systems called 'WaterGroup'. The goal of the experiment was to evaluate the impact of the SDSS on the collaborative decision process. The authors' definition of impact referred to the ability of the tool to achieve 'meaningful stakeholder participation' after providing stakeholders with information about water resources within a collaborative decision situation. The decision process was characterized in terms of human-computer-human interaction and the experiment goals were framed into a number of research questions. The tool was tested with two groups of stakeholders in a controlled experiment consisting of two workshop sessions, each group with a different software-facilitator configuration. Participants were asked to use the tool to create and select a water resource management plan for the region. Participant interaction and software use were registered with video cameras and computer activity logging. All participants were asked to fill out questionnaires before and after the sessions to record their perception on the software and the decision process. Results of this experiment showed that different technology configurations encourage a different balance between analysis and deliberation activities of spatial decision-making processes.

In an empirical study, Dias (2007) utilized an assessment methodology framework to measure and quantify the impacts and added value of contextual mobile spatial information services on 416 visitors of natural areas. This methodology involved comparing different information dimensions (e.g., having the information or not) and different information mediums. Pre and post-questionnaires were used to collect data on the spatial behavior, perceptions and opinions. Impact was measured with contingent valuation of information using preferences stated by the participants. This study found that the perception of added value increases when tool information becomes more detailed. A study by Salter et al. (2009) aimed to evaluate the impact of a participatory planning workshop. The authors categorized effectiveness into three aspects: 1) effectiveness of the workshop sessions; 2) effectiveness of the interactive spatial decision-support tools for landscape planning and its components; and 3) participants' feedback on the resulting plans. Planning workshops were held with experts involved in the planning process. In the workshops, the participants had the opportunity to explore, discuss and numerically assess different landscape scenarios on several indicators using an interactive planning tool. This evaluation was conducted using data collected through three methods: 1) pre and post-session questionnaire on the helpfulness of the workshop components and the tools; 2) video analysis; and 3) researcher observations. Participants' input suggested that the tool and its components helped them increase their understanding of the resulting plans. Salter et al. (2009) concluded that this type of mixed technology for tool and process evaluation constitutes a potentially useful means for measuring participant interactions in this type of workshops. A similar study by Sheppard and Meitner (2005) reported on the evaluation of an MCA-based SDSS by stakeholders of a sustainable forest management planning process. All participants were asked to provide feedback on the planning process and its individual components, such as focus group, criteria weighing, scenario evaluation and visualization. Martinez-Santos et al. (2010) discussed strengths and weaknesses of two tools for participatory water management with respect to each stage of participatory integrated assessment. The tools, namely Bayesian belief networks and hydrological modelling, were tested on a stakeholder group of a groundwater management process in the Mancha Occidental aquifer, Spain. An important conclusion is that a combination of the tools is more desirable for process support that each tool alone, since the former tool was considered more valuable for prompting stakeholder dialogue and the latter for communication of information. Other studies that examined the impact of spatial information and tools on a decision process agree that the degree of interactivity of a tool is an important aspect that can influence decision-making (e.g. Andrienko and Andrienko, 2003; Bacic et al., 2006; Goosen et al., 2007).

This section presented a number of empirical studies that focused on measuring the effectiveness of collaborative SDSS. These studies used a range of data acquisition methods such as surveys, questionnaires, observation, video analysis, screenshot analysis and user activity tracking techniques. A common aspect of the majority of these studies is that the assessments were largely based on user opinion and perception. Only a couple of studies actually included quantitative performance measures. Hence, this review suggests that there is a shortage in the literature of studies on the quantitative measurement of effectiveness of SDSS. The following section describes the empirical part of the present study, which involves the analysis and comparison of qualitative and quantitative measures on the basis of the three aspects of effectiveness.

4.3. Design of the experiment

4.3.1. Supporting collaborative planning for a polder in the Netherlands

This article analyzes the effectiveness of a set of tools developed to support the land use allocation problem in the Bodegraven polder in the Netherlands. The tools were developed to support a series of planning workshops with governmental and non-governmental stakeholders (see Chapter 2, Section 2.3, for details on the polder's allocation problem and the planning support workshops). This article focuses on testing the tools of the third workshop of the series, the negotiation workshop. Prior to this workshop, a series of experiments using M.Sc. students as participants was conducted to test the negotiation tools. For these tests, real stakeholders were not used for two reasons: first, with real stakeholders is not feasible to test different types of support; and second, with real stakeholders, it is difficult to distinguish between the influence of specific knowledge of these stakeholders and the influence of the tool.

4.3.2. Decision support tools

Three decision support tools were tested. The tools provided users with feedback information in three different ways: 1) as colors on multiple printed maps; 2) quantitatively on one digital map using numbers; and 3) qualitatively on one digital map using letters. The tools were developed with CommunityViz Scenario 360 (http://www.communityviz.com/). Technical details can be found in Arciniegas et al. (2011). In all three tools, spatial MCA was used to show trade-offs between objectives across the area. Weighted summation was used to aggregate standardized criterion values into performance scores for objectives and an overall performance score. To calculate the objective values, criterion values are first standardized between 0 and 10 and then multiplied by their weights. Next, the objective values are obtained as the sum of these products. The total value is calculated as the weighted sum of the objective scores (Janssen, 1992). The weights represent the relative importance of the criteria or objectives. Criterion weights were set and specified using expert judgment. Equal objective weights were used to calculate the total value in Figure 4.1. These weights can be adjusted during the workshop. In this application, the objective and total values are first calculated for each parcel. This results in value maps for each objective and a total value map. The values for the area as a whole (as presented in Figure 4.1) are calculated as the area weighted average of the values of all parcels. Stakeholders used the tools to identify trade-offs, agree on an exchange of land use and change land use patterns on the Touch table (see Chapter 2, Section 2.3, for a technical description of the table. To change the land use of one of more parcels, stakeholders use their fingers to select a land use class and then allocate it to selected parcel(s) on the Touch table. Figure 4.1 shows the values of the four objectives, as well as the total value for the entire study area. The dashed lines on each bar indicate the single objective maximum for each objective. If the participants changed the land use of one or more parcels, the values were automatically reassessed in real time. This information was available in combination with the different support tools on a separate screen.

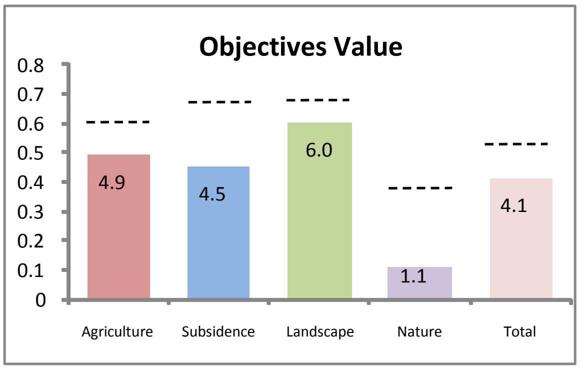


Figure 4.1. Objective values and Total MCA value.

4.3.2.1. Tool 1: Multiple-map colors

This tool consists of three choropleth classified maps printed in A3 format (Figure 4.2). Each map shows a classification of standardized objective values into ten equal classes, which are depicted in a red-to-green color ramp and rendered on a base polygon map (scale 1:50000) representing land parcels in the polder. The first of the three maps shows the potential value of the nature objective if the land use for the whole area would be nature. This map shows the best parcels for nature (green), the worst parcels for nature (red) and parcels in between. The second and third maps do the same for extensive and intensive agriculture. The three maps were available to all participants of a session. Participants can use these maps to support the identification of parcels that may profit from a land use exchange. Trade-offs between objectives can be identified, for example by looking at two or more maps at the same time.

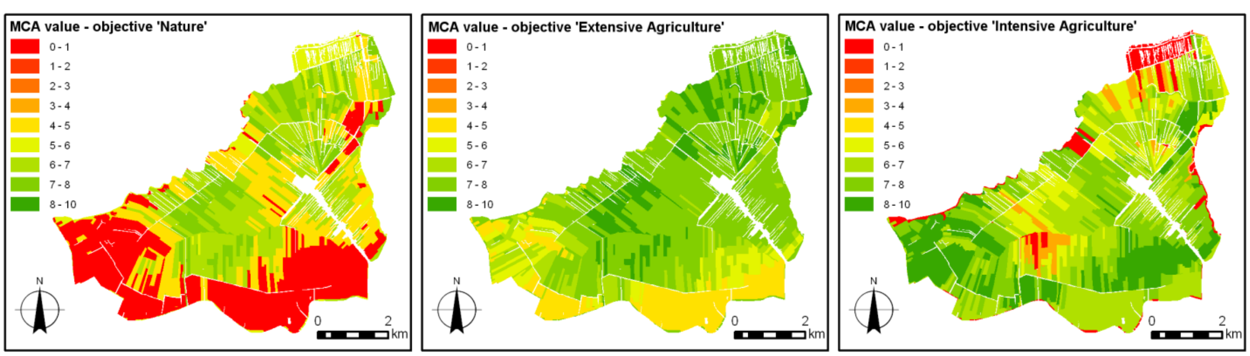


Figure 4.2. Feedback as colors on multiple objective-specific printed maps.

4.3.2.2. Tool 2: Single-map quantitative

This tool presents the objective values that are linked to the three types of land use in one digital base land use map (1:50000) on the 'Touch table'. The base polygon map shows a land use classification into three categories, which represent the current land use of a parcel. The values for the three objectives are shown on each parcel as a three-number label as follows: the first number represents the value of the parcel if it would be used for nature; the second for extensive agriculture; and the third intensive agriculture (see Figure 4.3). For example, the parcel in the top right of Figure 4.3 is currently in use for intensive agriculture. The three numbers in the parcel (7-7-4) indicate that the value is low for intensive agriculture (4) and would improve if it was changed to nature (7) or extensive agriculture (7). It is assumed that stakeholders try to obtain parcels that have a high value in exchange for a parcel with a low value. On the map, this means that participants will look for high/low and low/high combinations to identify parcels that are candidates for a favorable exchange. While most parcels in Figure 4.3 have land use intensive agriculture, not all of these parcels have a high value for intensive agriculture. If this low value goes together with a high value for another land use, this parcel becomes a good candidate for exchange. To support negotiation, the tool highlights trade-offs between objectives by coloring the boundaries of those parcels that are potentially favorable for an exchange of two land use types. In order to highlight trade-off information, users utilize an interface which appears on the Touch table on request. The interface has a number of interactive sliders, with which users can specify high or low thresholds for scores of each objective. Thresholds are set by touching and dragging one slider to a desired position. For example, the interface can be used to highlight parcels holding nature values higher than 8 and values for intensive agriculture lower than 1. Figure 4.3 shows that, based on this setting, a parcel with values 8-7-1 gets its boundaries colored in pink. This tool supplies the most information of all three.

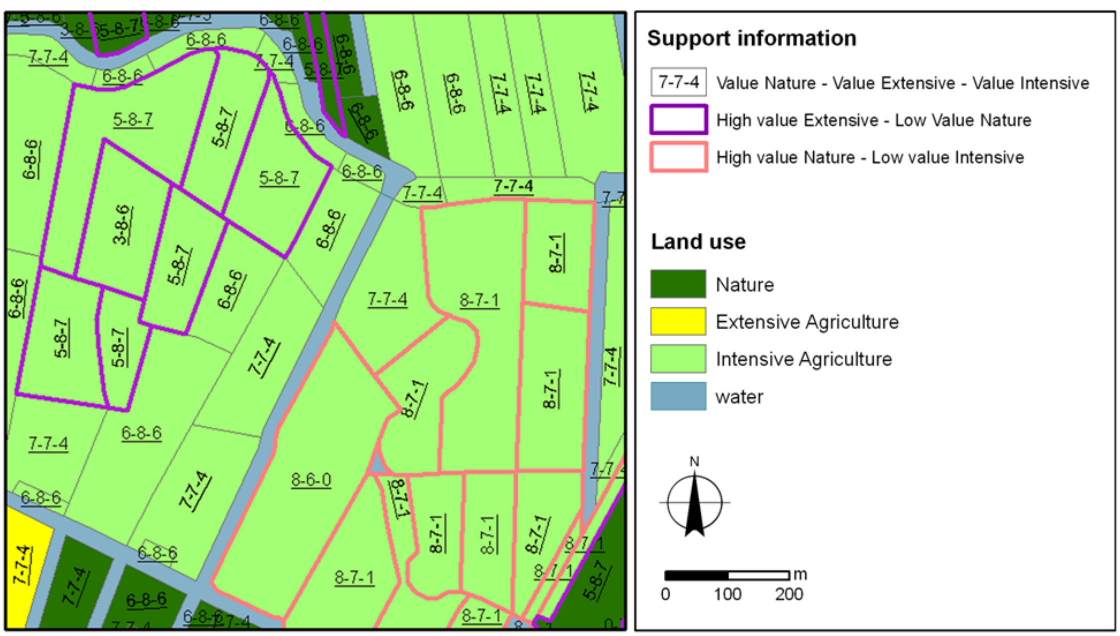


Figure 4.3. Quantitative feedback on a single digital map. Trade-offs are highlighted with color-coded boundaries.

4.3.2.3. Tool 3: Single-map qualitative

This tool provides qualitative feedback on a digital land use map on the ‘Touch table’. With this tool, participants can select and identify the best or worst parcels for each land use on the basis of the objective values. The tool features an interface, similar to that of the single-map quantitative tool, which appears on the Touch table on request and has interactive sliders for each objective. By touching a slider and dragging it to a new position, users specify a percentage of the study area (or the equivalent in hectares) to be analyzed and ranked on the basis of the objective values. For example, depending on the assignment, participants can use the tool to highlight the best 20% of all parcels with the highest score for land use ‘nature’ and the 20% with the lowest scores for land use ‘intensive agriculture’. In each parcel, a sequence of one, two or three characters is displayed representing the objective values associated with the three land uses. This tool is based on the assumption that participants will look for high/low and low/high combinations to identify parcels that are candidates for favorable exchange of land use between participants. With the tool, participants specify the size of the area in hectares to be included in the negotiation. For each land use, the tool selects the relatively best and worst parcels adding up to the specified area size. A fixed sequence of three characters, with each character representing a land use type, is used to identify selected parcels as follows: good (high value) parcels are labeled with blue characters and bad (low value) with red (Figure 4.4). The negotiation map shows the best (blue) and worst (red) parcels for each of the three land uses: Nature (N), Extensive Agriculture (E) and Intensive Agriculture (I). For example, a sequence of characters ‘N E I’, colored respectively blue, blue and red, indicates that a parcel falls within the best area for Nature and Extensive agriculture and within the worst for Intensive agriculture. If these parcels are currently in use for intensive agriculture, they make good candidates for exchange. Parcels that are not within the specified limits are left blank.

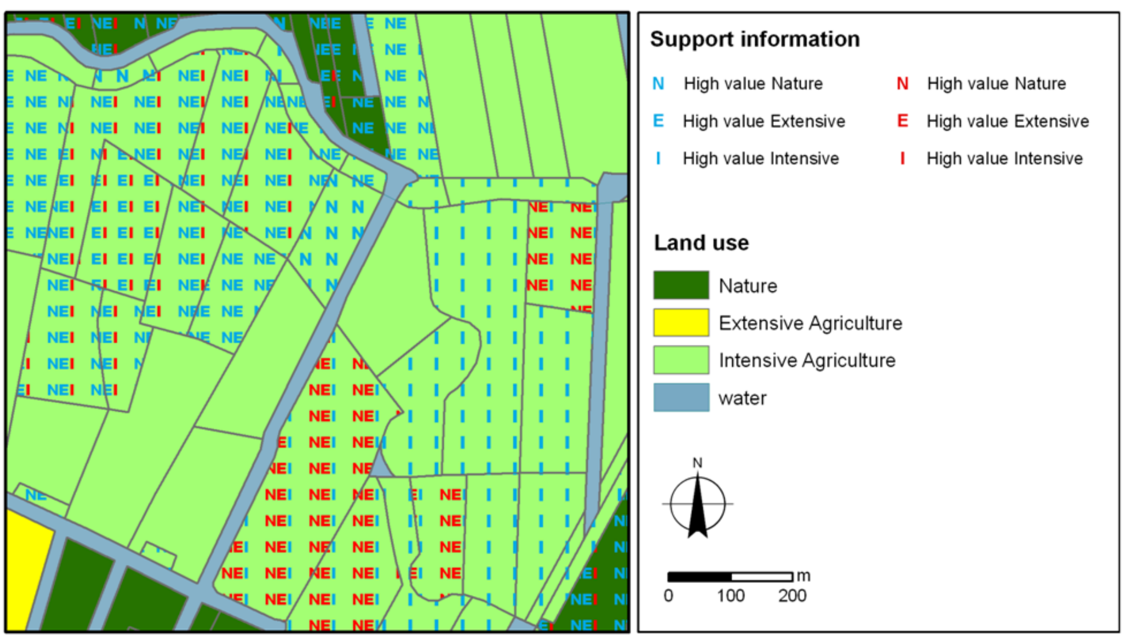


Figure 4.4. Qualitative feedback on digital maps. Trade-offs are highlighted with color-coded labels.

4.3.3. Hypotheses of experiment

Four hypotheses are tested to evaluate the effectiveness of the three support tools:

Hypothesis 1. The perceptions of tool effectiveness run parallel to the performance outcomes on a group level.
Hypothesis 2. The amount of information supplied in the tools affects the participants' understanding of the tools.
Hypothesis 3. The intensity of tool use affects the performance outcomes on a group level.
Hypothesis 4. The individual performance in using the tools influences the outcomes on a group level.

4.3.4. Setup of the experiment

4.3.4.1. Participants

Thirty people participated in the experiment. All participants were international students from the M.Sc. program in environment and resource management of the VU University Amsterdam. The majority of participants had an academic background in economics, environmental management, biology, or international relations. Participants were asked to carry out an assignment three times. Each time, they used a different support tool in an order defined randomly. For each tool there was both an individual and a group assignment. At the end of each assignment, they were asked to rate their experience with the tool and to answer a couple of questions related to their understanding of the tool and the information used.

4.3.4.2. Hardware

The layout of the experimental session is illustrated in Figure 4.5. Three participants were seated at the Touch table (display area of 86 cm x 65 cm), which was the interface to the tools. The graph of Figure 4.1 showing the objective and total values for the whole area was displayed on a separate screen. An observer stood beside the Touch table. A digital video camera recorded all sessions and stood to the left of the screen capturing all interaction among participants and between them and the Touch table. This experimental setup builds upon the format of earlier studies, such as Nyerges et al. (2006) or Salter et al. (2009), in which cameras, observations, questionnaires, or computer activity logging were used to record interactions between participants and systems in a workshop setting.

4.3.4.3. The assignment

The experiment involved ten 2.5-hour sessions. Each session included a group of three participants. These participants were asked to complete both a group and an individual assignment. The assignments were repeated for all three tools. In the group, each participant was asked to play a stakeholder role from the three possible roles (nature organizations, agricultural nature organizations, farmers' organizations) and increase the quality of a specific objective (Nature, Landscape, Agriculture). At the same time, each group was asked to increase the total quality of the reference plan as they tried to achieve long-term provincial policy goals in hectares for each land use. The group assignment was to:

- Allocate 400 ha of land use *Nature*
- Allocate 400 ha of land use *Extensive Agriculture* and 2755 ha of *Intensive Agriculture*

- Maximize the values of the three objectives and the *Total* value
- Try to connect parcels with land use *Nature*

The individual assignment was a simplification of the group assignment. Each participant was asked to use a tool separately to modify a land use situation within a subset of the study area. Specifically, each participant was asked to play the role of the stakeholder ‘Nature organizations’ and within 5 minutes relocate 100 ha of land use *Nature* reaching the following goals:

- Relocate 100 ha of *Nature*
- Maximize the *Nature* value and the *Total* value
- Try to connect parcels with land use *Nature*

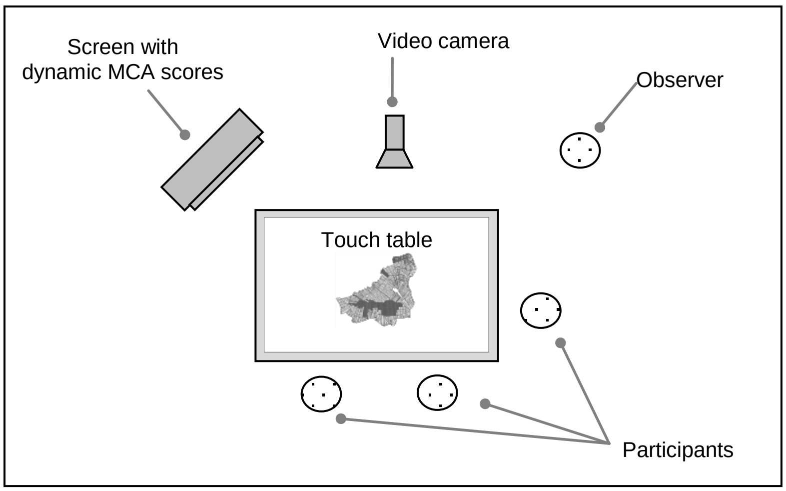


Figure 4.5. Arrangement of participants and hardware for the sessions.

The timeline of one experimental session is illustrated in Figure 4.6. The session began with an introduction to the study area and a short explanation of the tools followed by some hands-on practice with the tool. Next, both the individual and group assignments were explained, followed by a pre-session questionnaire. After introducing the first tool, each participant was asked to carry out the individual assignment using the first tool, one participant at a time. As soon as the third participant completed the assignment, all three were asked to collectively carry out the group assignment using the first tool. After completion, all participants were asked to individually fill out a questionnaire about their perception on the effectiveness of the tool and the entire system and to test their knowledge of the tool with which they just worked. These steps were repeated for the second and third tool. Once the work with the third tool was completed, a post-session questionnaire was administered to the participants.

The questionnaire records the effectiveness as perceived by the participants. The actual performance of the participants was monitored by means of an observer, video film, MCA scores and spatial patterns of plans. The observer kept track of the activities of the participants during the individual assignment and the interaction between participants during the group assignment. For example, the observer was to check whether or not a participant chose the right map or correctly used a support tool to complete an individual task, or kept track of how many times a group referred verbally to the information included in a tool in order to discuss one idea. Video film was used to acquire data on conflict management, time spent using support tools and time spent discussing. MCA scores and spatial patterns were used as an indicator of the quality of the plans generated by the participants.

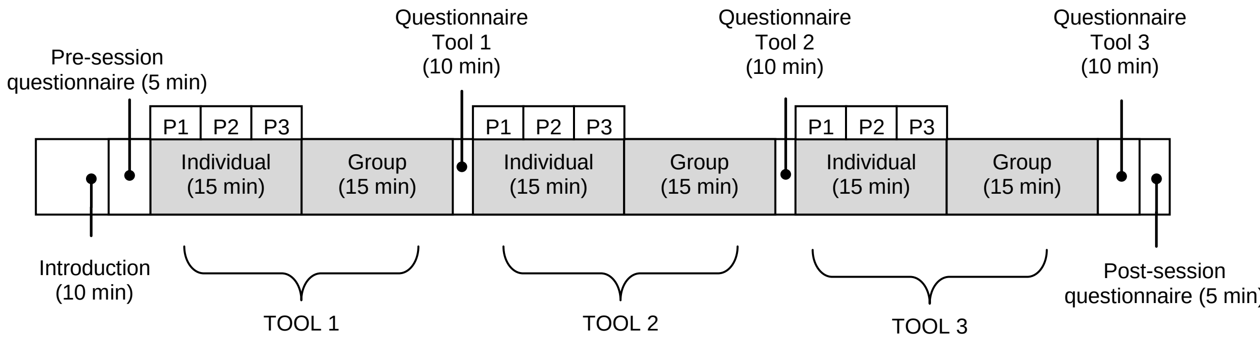


Figure 4.6. Timeline representing the experiment protocol of one session.

This assignment can be considered a form of scenario generation and evaluation. The products of both individual and group assignments are a set of future land use scenarios for the study area. Individual participants use the tools to generate scenarios for a section of the polder, while the groups generate collectively scenarios for the entire polder. All scenarios are evaluated using MCA on the basis of stakeholder objectives, as described in Section 3.2. Similar studies have included scenario evaluation assignments to test SDSS (e.g., Pettit, 2005; Kennedy and Bishop, 2008; Salter et al., 2009).

4.3.4.4. Limitations

The present empirical approach has three main limitations. First, using students as test subjects instead of real stakeholders can be an issue mainly for two reasons, namely a lack of local knowledge and a younger age, which implies a presumably higher acceptance of the technology being tested. However, the fact that students have neither local knowledge nor stakes concerning the study area can contribute to a more transparent evaluation of tool effectiveness, since it excludes the effect of local knowledge on the decisions. This effect might in fact be measured by comparing results obtained with students against those obtained with real stakeholders (e.g., in Pettit et al., 2011) or by comparing results obtained with and without the tool. In addition, while students can be more willing to embrace new technology, survey results from other studies that tested similar technologies with stakeholders relatively older and/or with less education than M.Sc. students revealed no significant difference in the acceptance of the technology (e.g., Alexander et al., 2012; Arciniegas et al., 2011). Second, having the same group of participants work with all three tools and the sequence of tool exposure could have had an effect on the outcomes that could be associated with carryover and learning effects (e.g., they might have become more skilled and efficient with every assignment). It would have been ideal to include all possible sequences of tool exposure in the analysis, allowing sufficiently long periods between each tool exposure, so that participants can disassociate themselves with the assignments and tools they just worked with. However, this proved to be impossible to realize due to limitations of time and student availability. Third, the relatively small sample size (30) might have influenced the precision of results. A larger sample size would have provided more statistical significance. Although online access to tools could have allowed for larger audiences (e.g., Meng and Malczewski, 2009), the present approach considers personal interaction an essential aspect of the tools tested. The hardware setup of the land use allocation tools of this approach required participants to interact with each other to allow give-and-take around the Touch table.

4.4. Results of experiment

Of the thirty subjects who took part in the experiments, 23% have a background in economics, 17% in environmental management, 10% in international relations and 10% in biology. Furthermore, 24% have some or considerable experience with digital maps, 16% with GIS and 48% with MCA.

4.4.1. Individual measurements

Data on individual perceptions regarding the tools were acquired from the participants' responses to the questionnaires. These responses are organized on the basis of the three aspects of effectiveness (F1. Usefulness; F2. Clarity; and F3. Impact). Table 4.1 summarizes these responses, indicating scales of measurement for every indicator (I) and detailed indicators (D). Participants rated the tools by specifying one level of satisfaction for a specific aspect using a 7-level Likert scale. This rating scale has three negative levels of satisfaction (-3, -2, -1), one middle neutral level (0) and three positive levels (+1, +2, +3). Such a scale has been used in previous empirical studies on tool effectiveness (e.g., Dias, 2007; Inman, 2011).

Table 4.1. Average perceived effectiveness per tool. A figure in bold denotes maximum, in italics denotes minimum.

		Multiple-map colors	Single-map quantitative	Single-map qualitative
F1. Usefulness of tool (questionnaire)				
I1. Usefulness of tool	Likert: -3 to +3	2.267	*1.600*	**2.483**
D1. Usefulness to identify trade-offs	Likert: -3 to +3	**1.867**	*1.414*	1.767
D2. Usefulness to support swaps	Likert: -3 to +3	2.000	*1.345*	**2.067**
D3. Usefulness to address conflict	Likert: -3 to +3	1.900	*1.036*	**1.931**
F2. Clarity of tool (questionnaire)				
I1. Clarity of tool information	Likert: -3 to +3	2.067	*1.700*	**2.267**
F3. Impact on decision process (questionnaire)				
I1. Valuation of tool	Likert: -3 to +3	1.222	*1.037*	**2.464**
I2. Influence of tool on decisions	Likert: -3 to +3	1.593	*1.519*	**2.407**
I3. Performance of plan	Single choice: %	*3.6*	17.9	**78.6**
Preferred support tool	Single choice: %	*10.7*	21.4	**67.9**
OVERALL PERCEPTION	Likert: -3 to +3	1.700	*1.378*	**2.119**

Data on individual performance is organized on the basis of the three aspects of effectiveness (F1. Usefulness; F2. Clarity; F3. Impact) (Table 4.2). The first aspect (F1) refers to the ability of a participant to execute a number of individual tasks necessary to complete a favorable land use exchange. Data were acquired by observer notes, which indicate whether or not a participant successfully completed a specific task. The second aspect (F2) shows whether or not a participant answered correctly a multiple-choice question about the information included in each tool. Concerning tool 1, participants were asked the following question: *what does it mean that one portion of the study area appears as red on one map and green on the other?* Concerning tool 2 and 3, participants were asked the same question twice: *by setting values with the interface, a number of parcels are highlighted on the map. On which basis are these* *parcels selected?* The third aspect (F3) comprises two measurements: Total MCA scores of plans and the number of parcels with a new land use.

Table 4.2. Average observed individual performance per tool. A figure in bold denotes maximum, in italics denotes minimum.

		Multiple-map colors	Single-map quantitative	Single-map qualitative
F1. Usefulness of tool (observer notes)				
D1. Identify trade-offs	yes=1/no=0	33.3%	**70.0%**	*25.9%*
Identify own valuable parcels	yes=1/no=0	*83.3%*	**86.7%**	**86.7%**
Identify others' valuable parcels	yes=1/no=0	*40.0%*	60.0%	**86.7%**
D2. Performance swaps				
Negotiate swaps	yes=1/no=0	*40.0%*	*40.0%*	**96.7%**
Carry out swap	yes=1/no=0	*40.0%*	*40.0%*	**60.0%**
D3. Performance conflict	yes=1/no=0	**80%**	*40%*	*40%*
F2. Clarity of tool information (questionnaire)				
C1. Test of subject's understanding	yes=1/no=0	*36.7%*	**80.0%**	70.0%
F3. Impact on decisions (MCA scores and spatial pattern)				
C1. MCA score normalized by min-max range [1]: 4.17-4.40	0 to 10	*1.568*	4.490	**5.325**
Increase in MCA score; reference = 4.17	0 to 10	*0.036*	0.103	**0.122**
C2. Parcels with a new land use	Count	**57.33**	*40.30*	44.20

[1] Normalization was performed using 4.17 as the baseline Total Score of the reference situation. The Score of 4.40 was obtained through linear optimization using the area goal of the individual assignment.

According to the results in Table 4.1, the participants found that the single-map qualitative tool was the most useful, the clearest and had the highest impact on their decisions. Conversely, the single-map quantitative tool received the worst valuations on these three aspects. The qualitative tool was considered to be the best for supporting all tasks, except 'identify trade-offs', which was thought to be best supported by the multiple-map colors tool. The overall perception was that the qualitative tool was the best and the quantitative the worst. According to observed performance (Table 4.2), the qualitative tool allowed for the best individual performance in the execution of all tasks, except 'identify trade-offs', which was best supported by the quantitative tool. The multiple-map color tool was not really understood by the participants, as only 36.7% gave a correct answer. Both the quantitative and qualitative tools were understood by 80% and 70% of the participants, respectively. MCA results show that the qualitative tool helped participants produce the plans with the highest MCA value, whereas the multiple-map color tool helped produce plans with the lowest value.

4.4.2. Group measurements

Data on group performance were collected from observer notes, video footage and the land use plans generated by the groups. Table 4.3 presents these measurements on the basis of the three aspects of effectiveness (F1. Usefulness, F2. Clarity and F3. Impact). Data on usefulness were obtained from the resulting land use plans as the Total MCA score of each plan. Data on clarity originated from the participants' answers to the test of knowledge. Data on impact are presented in five categories: 1) intensity of collective tool use; 2) time measurements; 3) group strategy; 4) conflict management; and 5) performance of plans generated.

Table 4.3. Observed average group performance per tool. A figure in bold denotes maximum, in italics denotes minimum.

		Multiple-map colors	Single-map quantitative	Single-map qualitative
F1. Usefulness of information (MCA scores)				
C1. MCA score normalized by range [2] 4.11-4.52	0 to 10	6.10	*5.12*	7.32
F2. Clarity of tool information (questionnaire)				
C1. Test of subject's understanding	yes=1/no=0	*36.7%*	**80.0%**	70.0%
F3. Impact on decisions				
C2-a. Intensity of tool use (observer notes)				
Discussed ideas	Count	*12.30*	14.20	**16.78**
Use of tool information	Count	13.70	*6.60*	**15.60**
Change land use	Count	13.10	*8.90*	**13.20**
Using chart with MCA scores	Count	8.10	*7.90*	**8.30**
C2-b. Time using tool (video)				
Time spent discussing	min:sec	**4:25**	*2:14*	2:48
Time spent working on Touch table	min:sec	**10:50**	*8:25*	9:18
Time spent using chart MCA scores	min:sec	**1:13**	*0:46*	0:58
C2-c. Group strategy (observer notes)				
Group discusses strategy before starting	yes=1/no=0	*60%*	*60%*	**80%**
Group refers to information presented in tool	yes=1/no=0	**100%**	*90%*	*90%*
Group refers to MCA information on screen	yes=1/no=0	**80%**	67%	*56%*
Two participants negotiate at once	yes=1/no=0	**40%**	30%	*20%*
Three participants negotiate at once	yes=1/no=0	*60%*	**70%**	*60%*
C2-d. Performance conflict (observer and video)				
Conflict emerged	yes=1/no=0	**80%**	*40%*	*40%*
Information of tool considered	yes=1/no=0	**100%**	*75%*	**100%**
Extent of use of tool	0 to 3	**1.90**	*0.60*	1.00
C3. MCA scores and spatial pattern				
C3-a. MCA score normalized by range [2] 4.11-4.52	0 to 10	6.10	*5.12*	**7.32**
Increase in Total MCA score; reference = 4.11	0 to 10	0.25	*0.21*	**0.30**
C3-b. Number of parcels with a new land use	Count	**303.1**	*202.0*	261.0
C3-c. Spatial pattern of land use map (clustering)	-1 to +1	**0.308**	*0.272*	0.289

[2] Normalization was performed using 4.11 as the baseline Total Score of the reference situation. The Score of 4.52 is the theoretical maximum value obtained through linear optimization of that score using the area goals of the group assignment.

Data on intensity of information use (C2-a) were acquired from observer notes and organized into four indicators. The observer counted how many times a specific task was carried out; for example, how many times the group consulted the tool to display trade-offs on the map, or how many times new land uses were reallocated to parcels. Time measurements (C2-b) were acquired from video footage and included two indicators for tool use and one for discussion. Data on group strategy (C2-c) were obtained from observer notes and organized into five indicators. For example, it was noted whether or not the group defined the strategy before starting the assignment or whether the decisions were made on a two-participant or a three-participant basis. Conflict management (C2-d) included three indicators, acquired from observer notes and video: whether or not conflict arose, whether the tool was used to address it and the extent of this usage. Plan performance (C3) comprises three indicators, which were obtained from the resulting land use plans: Total MCA scores of the plans (C3-a), the number of parcels with a modified land use (C3-b) and land use spatial patterns (C3-c). Table 4.3 shows that, in terms of intensity of use, the single-map qualitative tool was used the most intensively and also allowed for the most ideas discussed among participants. Time measurements show that the multiple-map color tool was used for the longest time and also prompted the longest discussions. As for group strategy, the multiple-map colors tool allowed for the highest scores for the most indicators. In terms of conflict management, the multiple-map color tool performed best. MCA results show that the groups generated the best plans with the qualitative tool and the worst with the quantitative tool.

4.5. Comparing perceived and observed effectiveness

4.5.1. Indicators of effectiveness for individual and group decision-making

This study analyzes the effectiveness of decision support tools on the basis of three dimensions: F1. Usefulness, F2. Clarity and F3. Impact. Each dimension is in turn measured with a number of indicators and validated through comparisons against observed measurements, or controls. Table 4.4 and Table 4.5 contain two frameworks for individual and group effectiveness, respectively, illustrating how each dimension is represented by indicators.

Table 4.4. Framework with dimensions, indicators and controls of effectiveness for individual decision-making.

Dimension	Indicator of perceived effectiveness	Control for observed effectiveness
F1. Usefulness of information	I1. Usefulness of tool D1. Usefulness to identify trade-offs D2. Usefulness to support swaps D3. Usefulness to address conflict	C1. Individual performance D1. Performance trade-offs D2. Performance swaps D3. Performance conflict
F2. Clarity of information	I1. Clarity of tool information	C1. Test of subjects' understanding
F3. Impact on decision process	I1. Valuation of tool I2. Influence of tool on decisions I3. Performance of plan	C1. Individual MCA Score C2. Parcels with a new land use

Table 4.5. Framework with dimensions, indicators and controls of effectiveness for group decision-making.

Dimension	Indicator of perceived effectiveness	Control for observed effectiveness
F1. Usefulness of information	I1. Usefulness of tool	C1. Group MCA Score
F2. Clarity of information	I1. Clarity of tool information	C1. Test of subjects' understanding
F3. Impact on decision process	I1. Valuation of tool I2. Influence of tool on decisions	C1. Group MCA Score C2-a. Intensity of tool use C2-b. Time using tool C2-c. Group strategy C2-d. Performance conflict
	I3. Performance of plan	C3-a. Group MCA score C3-b. Parcels with new land use C3-c. Spatial pattern of land use map (clustering)

To test how well the three dimensions together contribute to measure overall perceived effectiveness, a reliability analysis is carried out. This analysis is used to assess the consistency of results across specific items (i.e., dimensions for this study) within a test. It is used in this study to indicate how closely the dimensions (F1, F2 and F3) are as a group in relation to the three tools tested. The most common measure of reliability of scores for a sample is the coefficient of internal consistency, or Cronbach's alpha (Cronbach, 1951). A Cronbach's alpha of 0.70 or higher is generally considered as an "acceptable" value of internal consistency. For example, according to Table 4.4, usefulness (F1) is measured using three detailed indicators: (D1) *trade-offs, (*D2) s*waps* and (D3) *conflict*. Looking at Table 4.6, the coefficients for F1 (0.838, 0.805, 0.845) indicate high internal consistency, which guarantees that the three indicators are a reliable measure of perceived usefulness. Similarly, reliability indicators are calculated for F3. Acceptable coefficients of internal consistency make it meaningful to compute a general value of perceived effectiveness for each tool (see bottom row of Table 4.6).

Table 4.6. Reliability (Cronbach's alpha) of indicators of detailed perceived effectiveness for each tool.

	Multiple-map color	Single-map quantitative	Single-map qualitative
F1. Usefulness	0.838	0.805	0.845
F2. Clarity	-	-	-
F3. Impact	0.693	0.750	0.802
Overall F1, F2, F3 (alpha)	0.668	0.731	0.516

To compare the means of the measures obtained with each tool, paired samples *t*-tests were carried out. This test is recommended when different treatments are applied to the same participants and is also considered to be suitable for small sample sizes in similar studies (e.g., Inman et al., 2011). In this case, it is tested whether the difference between the measures obtained from two tools is different from zero. Since the traditional confidence interval for a mean difference is 95%, a significance value smaller than 0.05 indicates evidence that there is a difference in means across the paired observations. By running paired *t*-tests within the set of three tools, it is possible to establish whether the use of one tool leads to statistically different observations than another. For instance, it can be concluded that tool 1 is statistically different from the rest if two paired *t*-tests indicate that tool 1 is statistically different from tools 2 and 3. Table 4.7 and Table 4.8 summarize the results of the comparison between perceived and observed effectiveness as indicated in the frameworks presented, respectively, in Table 4.4 and Table 4.5.

Table 4.7. Comparison of average tool effectiveness for individuals [3]. A figure in bold denotes maximum, in italics denotes minimum and an asterisk (*) denotes a significant difference from the nearest neighbor.

Dimension	Indicator		Perceived effectiveness			Indicator		Observed effectiveness		
			Multi-map colors	Single-map quantitative	Single-map qualitative			Multi-map colors	Single-map quantitative	Single-map qualitative
F1	I1		2.267	**1.60*	**2.483**					
Usefulness		D1	**1.866**	**1.413*	1.767		D1	0.333	***0.700**	*0.259*
		D2	2.000	**1.345*	**2.067**		D2	*0.400*	*0.400*	***0.783**
		D3	1.900	**1.036*	**1.931**		D3	***0.800**	*0.400*	*0.400*
F2 Clarity	I1		2.067	**1.700*	**2.267**	C1		**0.367*	**0.800**	0.700
F3	I1		*0.714*	*0.714*	***1.563**	C1		**1.568*	4.490	***5.325**
Impact	I2		1.593	*1.519*	***2.407**	C2		***57.33**	*40.30*	44.20
	I3		*0.036*	0.179	***0.786**					
Overall			1.700	*1.378*	***2.119**					

[3] For details on indicators, refer to Table 4.4

Bottom row of Table 4.7 shows that the single-map qualitative tool has the highest average overall perceived effectiveness, which is significantly different to that of the other two tools. The single-map quantitative tool shows the lowest overall perceived effectiveness. In particular, the quantitative tool has the lowest perceived effectiveness for usefulness and clarity (F1, F2), both with a significant difference from the other two tools. Based on observed effectiveness, the single-map qualitative tool performs slightly better than the single-map quantitative tool, which in turn clearly performs better than the multiple-map colors tool.

Table 4.8. Comparison of average tool effectiveness for groups [4]. A figure in bold denotes maximum, in italics denotes minimum and an asterisk (*) denotes a significant difference from the nearest neighbor.

Dimension	Indicator	Perceived effectiveness			Indicator	Observed effectiveness		
		Multi-map colors	Single-map quantitative	Single-map qualitative		Multi-map colors	Single-map quantitative	Single-map qualitative
F1 Usefulness	I1	2.267	**1.60*	**2.483**	C1	6.098	*5.122*	***7.317**
F2 Clarity	I1	2.067	**1.700*	**2.267**	C1	**0.367*	**0.800**	0.700
F3	I1	*0.714*	*0.714*	***1.563**	C1	6.098	*5.122*	***7.317**
Impact	I2	1.593	*1.519*	***2.407**	C2-a	11.80	**9.200*	**13.25**
					C2-b	***04:07**	*02:51*	03:15
					C2-c	**0.680**	0.634	*0.612*
					C2-d	**0.800**	*0.400*	*0.400*
	I3	*0.036*	0.179	***0.786**	C3-a	6.098	*5.122*	***7.317**
					C3-b	**303.1**	**202.0*	261.0
					C3-c	**0.308**	*0.272*	0.289

[4] For details on indicators, refer to Table 4.5

4.5.2. Relationships between perceptions and observations

This section further analyzes the differences between the various tools by comparing the indicators in Table 4.7 and Table 4.8. The findings of this analysis are organized in terms of the hypotheses posted in Section 3.3. More specifically, this section compares the average levels of effectiveness for the three tools with a focus on:

1) The extent to which the overall perceptions on the tool effectiveness run parallel to the MCA scores achieved at group level
2) The relationship between the amount of information supplied and the MCA scores of groups
3) The relationship between intensity of tool use and the final MCA score
4) The relationship between the performance of individuals and the MCA score of a group

4.5.2.1. What is the relationship between the perceptions of tool effectiveness and the MCA scores

This question tries to find out to what extent the perceptions can match the results attained. Indicators to address this question are: overall individual perception of tool effectiveness (Table 4.7, last row); and group MCA score (Table 4.8, F3, C1). Overall, the participants found the single-map qualitative tool to be the best, which differed significantly from the other two tools. As Table 4.7 shows, this result is also consistent on usefulness, clarity and impact, and clearly shows that the single-map qualitative tool was found to be the most effective. These results mean that the perceived degree of tool effectiveness runs parallel to the Total group MCA scores achieved using the tools.

4.5.2.2. What is the relationship between the amount of information supplied and the MCA scores of the plans generated with the help of tools?

The amount of information users are able to handle is a relevant aspect of spatial decision-making. The associated cognitive effort, which is the mental effort that people use for processing information, can also be a relevant aspect. Indicators of observed Total MCA score achieved by individuals (Table 4.7, F3, C1) and by the groups (Table 4.8, F3, C1) are used to address this question. Individual MCA scores show that the single-map qualitative tool helped participants produce the best plans. The use of the multiple-map color tool resulted in the lowest scores. Group MCA scores show that the qualitative tool helped the groups produce the best plans. The worst group plans were obtained with the single-map quantitative tool. Apparently, the optimal SDSS configuration takes place if it provides information in a qualitative way. This may reflect that the use of the single-map quantitative tool requires a high cognitive effort that is beyond the participant's capacity. It may also be that users of the information systems are just more competent and effective when using qualitative data instead of quantitative data. Anyhow, irrespective of the underlying mechanism, it can be concluded that more precise information is not necessarily better than qualitative information and that even the opposite may occur.

4.5.2.3. Does the degree of discussion and cooperation triggered by the use of the tools have an impact on the group MCA scores?

When comparing the ranking of the three tools according to the group MCA scores (Table 4.8, F3, C1) with their performance in terms of their intensity of use of tool information, total time use and the extent to which they trigger collaborative strategies (F3, C2a-C2c), it is found in the first place that the three methods do not differ significantly in terms of the extent to which they trigger intensive group interactions, so this is not a strong factor to explain differences in MCA group performance. The total time use involved with the three tools is different, but the rank correlation with the group MCA score is low. The clearest relationship is found for intensity of use of tool information. The success of the single-map qualitative tool may well be due to the fact that it is in such a format that it stimulates group members to use the tool information in a large number of rounds.

4.5.2.4. What is the relationship between the performance of individuals to carry out specific land use allocation tasks and the Total group MCA score generated with the help of the tools?

This question relates to how the correct use of a tool affects the achieved results. To address this question, the following indicators are used: observed individual performance in the tasks 'identification of trade-offs', 'completion of land use swaps' and 'addressing conflicts in objectives' (Table 4.7, F1, C1, D1-D2-D3) and both individual and Total group MCA scores (Table 4.7, F3, C1 and Table 4.8, F3, C1, respectively). According to observed effectiveness, 70% of the participants used the single-map quantitative tool correctly to identify trade-offs. 97% of all participants used the qualitative tool correctly to perform land use exchanges. The multiple-map color tool proved to be the best in helping participants address conflicts of objectives. Group MCA scores indicate that the use of the qualitative tool resulted in the best plans. These results suggest that good individual performance in land use allocation tasks leads to plans with high MCA scores. The qualitative tool allowed for the best individual performance in executing swaps. The multiple-map color tool was the best to address conflict of objectives. Group MCA scores show that the single-map qualitative tool allowed for the best plans. It can be concluded that a good individual performance in spatial decision-making contributes to some extent to an increase in the Total group MCA score. Figure 4.7 shows that all groups succeeded in increasing the baseline Total score. It is also clear that the single-map quantitative tool provided the worst group results. Therefore, the qualitative tool was the most successful in increasing the Total score on both individual and group levels.

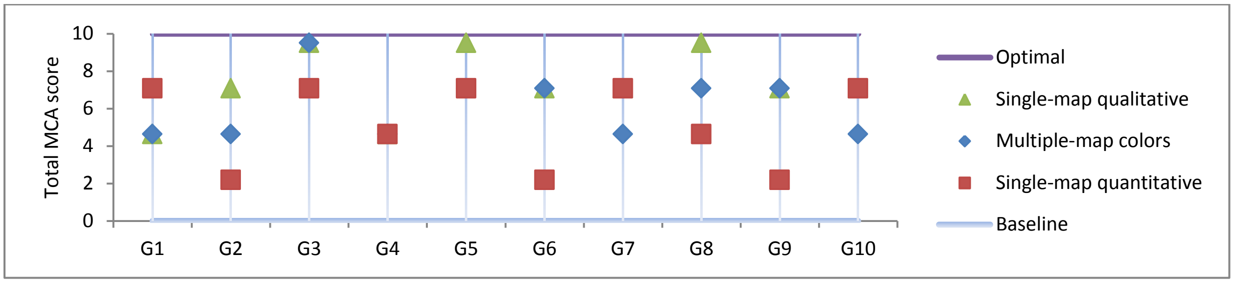


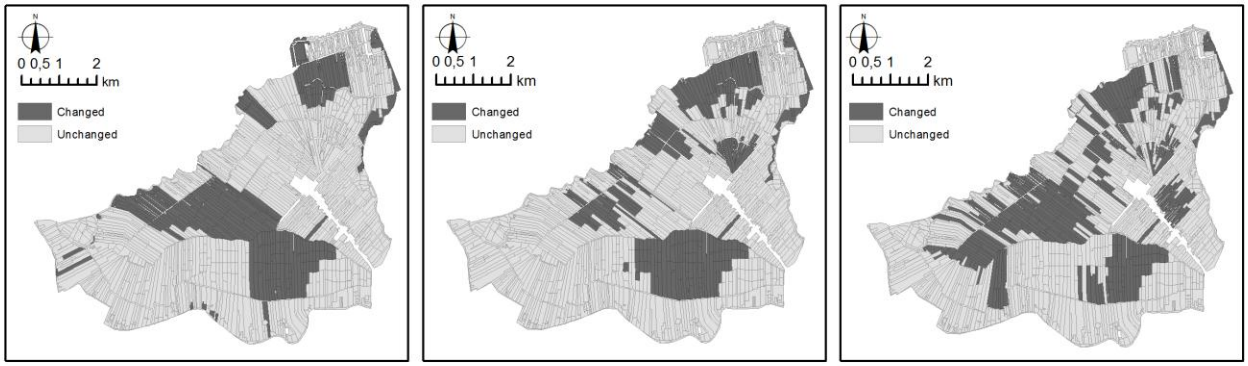
Figure 4.7. Observed Group effectiveness: Total MCA score for all groups.

4.5.3. Spatial effects of support tools

The above discussion focused on the quality of the changes in land use as measured by means of the overall indicator based on MCA. The actual land use changes and spatial patterns as they can be observed on a map have not been addressed thus far. This section discusses explicitly these dimensions, particularly how these changes relate to collaborative work. It looks particularly at indicators 'parcels with a new land use' (Table 4.8, F3, C3b) and Moran's value for spatial patterns of land use (Table 4.8, F3, C3c). Each group generated three land use maps, thus a total of 30 maps were generated by all groups.

4.5.3.1. Difference maps

To compare how different the maps are between the three tools and with respect to the reference land use situation, a difference map between two situations is created. A difference map shows whether or not a change in land use took place on a parcel after the use of a tool. Therefore, the legend of a difference map includes two non-overlapping classes: *unchanged* land use and *changed* land use. Figure 4.8 exemplifies the difference maps for the plans generated by Group 5. Parcels that have a changed land use with respect to the reference map are shaded dark. The map made with the single-map qualitative tool shows the most apparent differences. The same procedure was followed to create difference maps for all groups. Difference maps are important for two reasons. First, they focus on a very relevant aspect of land use planning: policy alternatives are not only represented in terms of their scores in 'objective space' where MCA scores are compared, but also in the physical space where the intervention in terms of proposed land use changes are represented. They are thus of direct relevance for participants in the process since they inform them on where the proposed land use changes will take place. The second reason is that by comparing them across various decision support tools, it becomes possible to analyze to what extent a certain tool is stimulating a more explorative attitude than others. This is important since one of the functions of SDSS is to stimulate and support creativity among participants in the decision-making process. A tool that leads to outcomes that are far away from the reference situation may be a sign that it supports a search outside the conventional domain.



Multiple-map colors | Single-map quantitative | Single-map qualitative

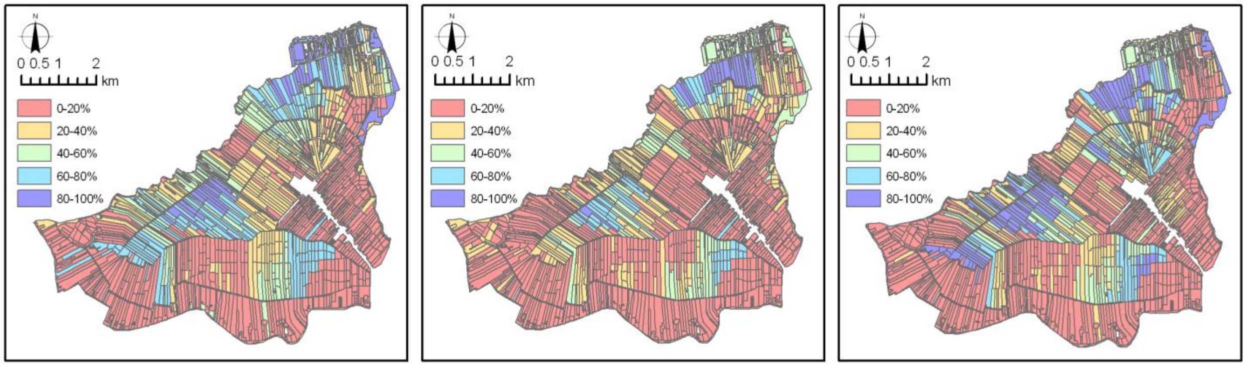
Figure 4.8. Changes in land use with respect to the reference situation for the three plans generated by group 5.

Table 4.9 summarizes the average number of parcels whose land use got changed as a result of the group assignment carried out by each of the 10 groups. The study area comprises a total of 1478 parcels. Statistically, just as in the individual assignment, the maps produced by the groups using the multiple-map color tool present the largest average of parcels with a modified land use with respect to the reference situation (as can be seen from Tables 4.2, F3, C2 and Table 3, F3, C3b). However, this result shows no significant difference to that of the qualitative tool. On average, the quantitative tool shows the least amount of unmodified parcels, again just as in the individual assignment. This result also matches observed results of group performance, namely strategic information use, time used for discussion and information use, and extent of information use to address conflicts.

Table 4.9. Average number of parcels with different land use. A figure in bold denotes maximum, in italics denotes minimum and an asterisk (*) a significant difference. Figure in brackets corresponds to percentage of all parcels.

	Reference	Multiple-map colors	Single-map quantitative	Single-map qualitative
Reference	-	**303.1 (21%)**	**202.0 (21%)*	261.0 (18%)
Multiple-map color	303.1 (21%)	-	**303.7 (21%)**	*300.1 (20%)*
Single-map quantitative	**202.0 (14%)*	**303.7 (21%)**	-	281.2 (19%)
Single-map Qualitative	*261.0 (18%)*	**300.1 (20%)**	281.2 (19%)	-

To compare the spatial results of each tool with each other, a similar analysis was conducted, having each tool as the reference. This analysis reveals no statistical difference among each possible pair of tools, meaning that there are no signs of learning in the sense that the groups would base their land use plans on the outcomes of earlier sessions. Figure 4.9 shows three maps that illustrate the percentage of land use change with respect to the reference plan. Table 4.10 summarizes these results. The bottom row of this table shows that the single-map qualitative tool has the largest number of parcels (100) whose land use was changed in more than 80% of all plans made by the groups, whereas the single-map quantitative tool allowed for the smallest number of parcels. This ranking matches those of Total group MCA score and observed intensity of tool use. The differences in tool performance are indeed reflected by the volume of proposed changes in land use. It appears that the single-map qualitative tool is most effective in exploring alternatives that are rather different from the reference situation. Although it is certainly not necessarily true that thinking ‘out of the box’ leads to better results, the present study finds that the two dimensions tend to be in harmony.



Multiple-map colors | Single-map quantitative | Single-map qualitative

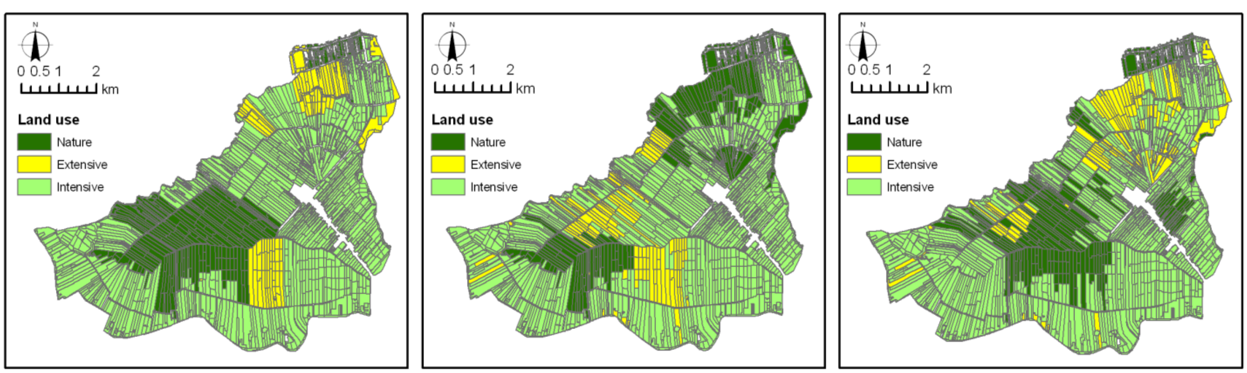
Figure 4.9. Probability that a parcel's land use is changed as the result of group decisions with each of the three tools.

Table 4.10. Distribution of probability that a parcel's land use is changed as the result of group decisions with each of the three tools. Figure in brackets corresponds to percentage of all parcels.

	Multiple-map colors	Single-map quantitative	Single-map qualitative
0-20%	860 (58%)	1013 (69%)	976 (66%)
20-40%	333 (23%)	351 (24%)	275 (19%)
40-60%	232 (16%)	89 (6%)	127 (9%)
80-100%	53 (4%)	25 (2%)	100 (7%)

4.5.3.2. Differences in spatial land use patterns

The spatial patterns of the maps produced by all groups with the three tools were compared with a spatial autocorrelation analysis. This analysis measures parcel similarity for one land use map based on parcel locations and land use types, evaluating whether the pattern is clustered, dispersed, or random. Spatial autocorrelation can be estimated with the Moran's I index (Moran, 1950). A Moran's I value near +1 indicates clustering, while a value near -1 indicates dispersion. Figure 4.10 shows the three maps generated by Group 5, each with its corresponding Moran's I value.



Multiple-map colors
Moran's I = 0.44

Single-map quantitative
Moran's I = 0.32

Single-map qualitative
Moran's I = 0.26

Figure 4.10. Difference in spatial pattern for the three plans generated by group 5.

By visual inspection, it becomes apparent that the map produced with the multiple-map color tool presents the most clustered land use patterns of the three maps, which is supported by looking at its Moran's I value. Moran's indexes were calculated for all 30 maps. Statistically, the maps produced on the basis of the multiple-map color tool present the largest clustering tendency (see Table 4.8, F3, C3c). This result is in agreement with that for spatial differences (see Section 4.5.3) as it matches observed group performance measures, namely land use change, strategic information use, time used for discussion and information use, and extent of information use to address conflicts. This suggests that the multiple-map color tool, which provides feedback as colors on printed maps, leads to plans of higher spatial consistency that those attained with the other two tools, which provide more detailed feedback on individual parcels.

4.6. Conclusions

MCA and GIS are promising tools for the translation of output of integrated models into integrated knowledge for policy makers. They may help to reduce the gap between the worlds of science and policy making. These tools can be combined in spatial decision support tools for collaborative decision-making, but the research assessing the effectiveness of these decision support tools is still ongoing. To date, there are no concrete guidelines in the literature about the evaluation of tool effectiveness. Previous empirical studies have typically reported on qualitative assessments, focusing on positive perceptions of end-users as a measure of success. This study takes a step forward by evaluating the effectiveness of three collaborative map-based tools on the basis of both user perceptions and objective measurements of performance in the execution of specific tasks. This evaluation is based on a framework that included tests of usefulness of tools, clarity of information and impact on decisions. In drawing conclusions, this section discusses the results on the basis of three aspects: first, the comparison between the tools tested; second, the comparison between individual and group decision-making; and third, the implications for integrated environmental assessment and policy making.

4.6.1. Effectiveness of map-based decision support tools

This section addresses the first three hypotheses posted in this study. The first hypothesis was: "*the perceptions of tool effectiveness run parallel to the performance outcomes on a group level".* Testing this hypothesis involved comparing the perceived effectiveness of each tool with observed group measurements. Of the three tools tested, the participants found the single-map qualitative tool to be the most useful, followed by the multiple-map color tool. These judgments largely match observations of individual performance: first, the use of the qualitative tool prompted the best individual performance in decision-making tasks linked to land use allocation, such as the identification of potentially favorable trade-offs on the map and the resulting reallocation of land use between the parcels in question; second, the use of the qualitative tool also resulted in the best plans on both an individual and a group level.

The second hypothesis, "*the amount of information supplied in the tools affects the participants' understanding of the tools*", relates to the clarity of the information presented in the tools. This hypothesis follows up on recommendations by previous studies (e.g., Kennedy and Bishop, 2008) that further controlled experiments can contribute to measuring how much knowledge of choices of participants using tools influences choice behavior. It was found that the tool with the highest information level, that is, the single-map quantitative tool, proved to be too difficult for the participants to use and was also considered by them to be the least useful. Using the quantitative tool thus resulted in the worst plans for both individuals and groups, despite a high participants' understanding of this tool.

For the third hypothesis "*the intensity of tool use affects the performance outcomes on a group level*", it was found that during the group assignment the qualitative tool was used the most extensively to support decisions. The use of the multiple-map color tool took the most time and prompted the longest discussions. Footage showed that when conflicts emerged during the negotiations, this tool proved to be the most used tool to address such conflicts. Overall, these findings suggest that presenting the same results of spatial MCA in different ways to support negotiated land use allocation leads to different outcomes, that is, land use plans. In this study, the use of qualitative feedback offered on parcels on one digital map led to the best land use plans both individually and collectively. Furthermore, the use of the multiple-map color tool also allowed for the spatially most different plans both on an individual and group level, and for the spatially most autocorrelated plans on a group level. Testing hypotheses 2 and 3 shows that, in this application, a low level of complexity in the information with which decision-makers are provided prompted extensive allocation work and led to overall results of higher quality. Previous studies reported different success rates of tools for different complexity levels of information supplied (e.g., Nyerges et al., 2006; Dias, 2007).

4.6.2. Individual vs. Group effectiveness

Measuring the extent to which the performance of individuals in using decision support tools influences group outcomes has not been explicitly studied in the literature. Most studies discussed in this article have only utilized individual perceptions of effectiveness in their analyses (e.g., Salter et al. 2009; Nyerges et al. 2006; Inman et al., 2011). The fourth hypothesis of this study, "*the individual performance in using the tools influences the outcomes on a group level*" addresses this issue. The average performance of individuals to achieve high-quality plans, that is, the Total individual MCA score, matches that achieved on a group level. With the single-map qualitative tool, the highest MCA scores were achieved both individually and collectively, and with a significant difference from the other two tools. In terms of observed individual task performance, it was found that the specific individual ability of the participants to identify and use potentially favorable trade-offs on the map has an effect on the quality of the results achieved as a group. In terms of group performance, some results correlated significantly with the Total group score. In particular, the extent of discussion among participants triggered by the use of the support tools proved to have both a positive and significant impact on the quality of group results. It can be concluded that irrespective of the type of information supplied to users, in this study both the individual ability to use this information to support negotiated exchanges on land use and the extent of the discussion triggered have an impact on the quality of the resulting land use plans.

Regarding the spatial configuration of the generated land use plans, the difference maps also showed a full correspondence between individual and group performance. In particular, the extent to which the spatial patterns of the reference situation were modified correlates with the sequence of tool exposure: the participants changed the land use of the largest amount of parcels on both an individual and a group level using the multiple-map color tool and the least amount with the single-map quantitative tool. This result also matched the individual MCA scores as well as group strategic information use, time used for both discussion and information use, and information use for addressing conflicts. It can be concluded that the individual performance to generate high-quality plans has an impact on the extent of discussion and strategic information use, which is also reflected on the relative spatial changes of the resulting plans.

4.6.3. Implications for integrated environmental assessment and policy making

On the basis of this study's specific experiment, a number of conclusions can be formulated that apply in a more general setting of collaborative SDSS. It was found that MCA and GIS are effective tools to provide intelligible information arising from an integrated model for policy contexts. The present experiment basically compared a number of tools involving different degrees of detail and ways of spatial representation of the integrated information. A major conclusion is that the cognitive effort required to understand different levels of information content is a serious issue in spatial decision support. The experiment showed that cognitive effort can in fact change with different approaches for presenting output information of spatial decision support tools. This holds true for both the amount of information, the level of detail of information to be supplied to end users and also for the format in which the information is provided. The single-map quantitative tool, being strong in detailed information on trade-offs between policy objectives, performed clearly worse than the multiple-map color and the single-map qualitative tool. Further empirical studies focusing on spatial tool development should explore the effects in terms of cognitive effort of the amount of information and detail provided in a land use planning support tool. The survey-based methodology of a study by Grotenhuis et al. (2007), which investigated how to reduce cognitive effort in travel information provision for public transport, can provide useful guidelines. Additionally, Nyerges et al. (2006) recommended software assistance by a facilitator-chauffeur to help reduce cognitive effort.

A second conclusion is that the perceived effectiveness of tools has a rather close relationship with observed effectiveness. The high-tech single-map quantitative tool was valued clearly lower than the low-tech multiple-map color tool. This means that the fear for risk of overestimation of the utility of high-tech decision support just because it gives the users a better feeling is not confirmed in this case. The conformity of this finding with the literature discussed in this article is not entirely clear. While Dias (2007) found that perceived added value increases when tool information becomes more detailed, Janssen and Uran (2003) concluded that a high preference for a decision support tool does not always relate to a successful use. Inman et al. (2011) reported that perceived effectiveness of tools is influenced by end-user's employment. Users of SDSS need training and time to play and get acquainted with the tools. The experiments showed that a considerable part of the participants involved did not fully grasp how the tools work. Nevertheless, all tools proved useful in terms of the improvement of the overall land use quality. The intensity of tool use is clearly correlated with the quality of the overall outcome. This result indicates that the various tools used were in fact useful for the group task: in the present experiment, SDSS do what they are supposed to do.

Furthermore, it appears that when a tool is more stimulating, it helps to achieve more effective use of information. Support tools appear to be rather different in terms of the extent to which the proposed alternative is far away from the reference situation. It appears that the tool based on qualitative information leads to alternatives that are further away from the reference situation compared with the other tools. Further research on how properties of tools trigger exploratory attitudes among participants in land use planning is recommended. The planning process, for which the tools were made, includes experts from many disciplines and backgrounds. Bringing these experts into one workshop could be called a form of integrated environmental assessment. In the workshop, information from all sources was presented as maps on the table. Using maps as the single means of communication and a common assignment on the 'Touch table' to stimulate cooperation proved to be a very effective means of communication between stakeholders with different backgrounds.

Prior chapters have discussed specific elements of the methodology discussed in this thesis and its application to the land use planning process of a peat-meadow polder. The following chapter provides a detailed description of the three workshops designed for this research as well as how the series can be integrated to support the land use planning process of the Bodegraven Polder. Chapters 2 and 3 have described the tools developed for the analysis and negotiation workshops, respectively. Next chapter introduces the design workshop, which starts the workshop series, in addition to the subsequent two workshops.

Chapter 5

Spatial decision support for collaborative land use planning workshops

Abstract

This article describes a series of collaborative land use planning workshops for a peat-meadow polder in the Netherlands. Three interconnected planning workshops were conducted with stakeholders: a design, analysis and negotiation workshop. Stakeholders were invited to work together and carry out planning tasks using spatial decision support tools implemented in an interactive instrument (the 'Touch table'). Goals, participants, tasks and tools were different for each workshop. The series began with a design workshop, in which stakeholders used drawing tools on the Touch table in order to transfer and process local knowledge. Next, in an analysis workshop, stakeholders used spatial multicriteria tools to combine different types of expert knowledge and generate feedback for quantitatively evaluating land use scenarios for the polder. The series ended with a negotiation workshop, where stakeholders used interactive land use allocation tools collectively on the Touch table to reach a consensus land use plan for the polder. Results from surveys conducted at the end of each workshop indicated that participants found the tools appropriate for a workshop setting. It is concluded that digital maps can be used effectively to support three different types of collaborative planning workshops that are a part of an ongoing land use planning process. Important aspects in the design of the workshops included the selection of participants, level of detail and complexity of spatial information provided and a balanced formulation of workshop assignments.

Focus: this chapter presents an approach for supporting land use planning processes through a series of three types of stakeholder workshops. The chapter focuses on the workshop activities, in particular the tasks carried out by the participants using the support tools presented in Chapters 2 and 3 and a set of drawing tools for the qualitative evaluation of land use plans.

Research highlights:

- We implement three types of collaborative workshops for land use planning.
- With design, analysis and negotiation tools, stakeholders work together on new plans on the Touch table.
- Spatial multicriteria analysis effectively clarifies trade-offs between objectives.
- The workshops are valuable means for incorporating knowledge into the decision process.

This chapter is based on: Arciniegas, G.A., Janssen, R., 2012. Spatial decision support for collaborative land use planning workshops. Landscape and Urban Planning, 107(2012), 332-342.

5.1. Introduction

Collaborative workshops are common in land use planning. Stakeholders using maps to discuss plans is not something that started in recent years. In the beginning, workshops were supported using large hard copies of maps in combination with sheets of tracing paper maps representing attributes of the proposed plan or plan area (Burrough and McDonnell, 1998). In following years, with the arrival of Geographical Information Systems (GIS), the transparent tracing map sheets were replaced by map layers presented within the GIS on a computer screen (Longley et al., 1999). Involvement of stakeholders has increased over the years. In the early years, the emphasis was on communication; in later years this shifted to participation where active involvement of stakeholders was required (Sieber, 2006). At present, the focus is on collaboration: stakeholders actively working together to reach the best compromise. Support systems evolved along with this development (Dragicevic and Balram, 2006). Undoubtedly, GIS was used widely in the early stages, mainly for providing spatial information rather than for interacting with it. A next step was the development of Participatory GIS (Carver, 2003; Jankowski, 2009), which focuses on improving human participation within group spatial decision-making and has evolved along two paths: Public Participation GIS (PPGIS) and Group Spatial Decision Support Systems (GSDSS). PPGIS focuses on improving public access to geospatial data and maps, providing possibilities for participatory learning and analysis by the general public, community groups and marginalized groups in planning and decision-making for their communities (Craig et al., 2002).The shift to collaboration created the need for GSDSS, which support the identification of trade-offs, conflict and compromise between stakeholder groups (Boroushaki and Malczewski, 2010).

However, Geertman and Stillwell (2009) state that despite a promising integration of technologies and a high number of pilot studies, the successful application of geo-technology by planning practitioners to support their activities is far from commonplace. Uran and Janssen (2003) identify the mismatch between the decision problem of end-users and the answers produced by the system as the main factor for this lack of success: technology-driven systems produce the correct answer to the wrong question at the wrong moment. Along the same lines, Geertman and Stillwell (2009) state that “there exists a fundamental dichotomy between those systems that are demanded for use in practice by potential users and those systems supplied by systems developers according to their perception of what is required”. This article describes the use of spatial tools in collaborative planning workshops to support a land use allocation problem in a peat-meadow polder in the Netherlands. As part of the planning process, a series of three interconnected workshops, namely design, analysis and negotiation, was organized with stakeholders. Specific tools were integrated into each workshop and implemented in an interactive mapping device called the ‘Touch table’. This article investigates the following research question: *how can spatial decision support tools meet the requirements of a collaborative land use planning workshop?*

The article consists of seven sections. Section 5.2 reviews recent approaches of collaborative spatial decision-making. Section 5.3 outlines the research methodology. Results are presented in Sections 5.4 to 5.6: Section 5.4 introduces the planning problem and presents the results of the design workshop; and Sections 5.5 and 5.6 present the results of the analysis and the negotiation workshop, respectively. Each of these three sections is concluded with a short evaluation of tool effectiveness. Conclusions are given in Section 5.7.

5.2. Supporting map-based collaborative spatial decision-making

There are numerous models to structure a decision process that have been applied to spatial decision-making. The model of Mintzberg (1976) identifies three stages: 1) identification and framing of a problem; 2) exploratory development of alternatives; and 3) selection and decision. Renn et al. (1993) distinguish three steps: 1) identification and selection of evaluative criteria; 2) identification and measurement of impacts of decision options; and 3) aggregation and weighting of impacts of decision options. Steinitz (1990) proposes a six-level framework that organizes questions associated with a landscape design problem. The community-based sustainability planning approach of Robinson et al. (2006) views a planning process as a social learning process in which expert knowledge is combined with public attitudes, preferences and beliefs in order to improve understanding of issues of sustainability. Figure 5.1 illustrates how each stage of the process can be supported with maps. Map use can be threefold: 1) to communicate spatial information to stakeholders; 2) as analysis tools for spatial evaluation of decision alternatives; and 3) as input for interactive tools for decision support. Maps can also be used to support feedback loops in the process (Andrienko et al., 2007).

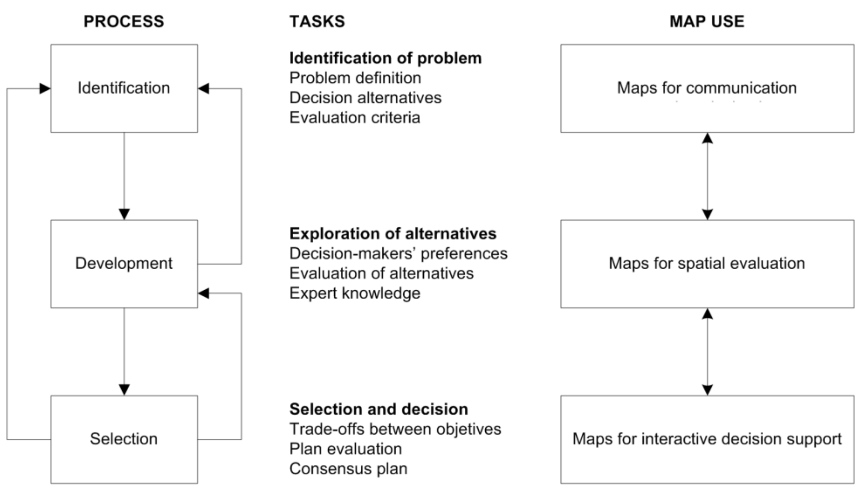


Figure 5.1. Supporting map-based collaborative land use planning.

5.2.1. Maps for communication

In addition to text, tables and graphs, relevant information for spatial decision-making can be presented on maps. Decision alternatives, locations of decision options, or spatial patterns are generally presented as maps (Kraak and Ormeling, 2003). Thematic or topographic maps can be used as background information to support discussions. Maps are often the stakeholders' preferred source of information for spatial decision-making, despite not being easy to understand and use (Janssen and Uran, 2003). Map presentation has also been used as a means to develop land use alternatives as well as to handle conflicts among stakeholders. Carton and Thissen (2009) utilized hardcopy maps for the development of a 'suitability map', which showed opportunities for land use change in a regional water management context on the basis of a set of criteria for suitability. This map consisted of several thematic maps overlaid with modifications made during stakeholder meetings. Primary stakeholders used printed versions of these maps to draw comments and suggest changes. This feedback was subsequently digitized and incorporated with GIS in the suitability map. Carton and Thissen conclude that the maps proved effective for supporting collaboration for designing new visions about water management. Other studies featured large-format printed background maps for drawing and presenting plans during collaborative planning sessions (e.g., Mayer et al., 2004; Vieira and Castillo, 2010). Landscape visualization has also been used for communicating spatial scenarios in stakeholder workshops about environmental problem solving and has proved useful for increasing stakeholders' understanding of a decision problem (e.g., Bishop et al., 2009; Sharma et al., 2011).

5.2.2. Spatial evaluation

Integrating Multicriteria Analysis (MCA) and GIS has contributed to the development of spatial tools for the analysis of decision alternatives. This integration provides methods to evaluate, compare, rank, map and present the performance of decision alternatives on the basis of several criteria and/or objectives (Malczewski, 2006). Jankowski et al. (2001) emphasize the role of maps as a source of structure in multiple criteria spatial decision problems. For example, Goosen et al. (2007) used MCA-derived value maps to compare spatial patterns of wetland management plans. Value maps for all stakeholders were derived by combining specific criteria maps using weights specified by users. Goosen et al. conclude that these maps are useful spatial evaluation tools for rapid assessment and visualization of strengths and weaknesses of management plans and recommend a combination of spatial MCA and negotiation support for a better balance between process-support and content-support within spatial decision-making. Other recent applications of spatial MCA for the evaluation of decision alternatives include the collaborative valuation of ecological qualities (e.g., Kokkonen et al., 2010; Recatalá and Zinck, 2008), integrated wetland management (e.g., Janssen et al., 2005), or participatory forest management planning (e.g., Greene et al., 2010; Sheppard and Meitner, 2005).

5.2.3. Interactive decision support

Map-based tools can be used interactively. Typical tools combine different methods, such as spatial MCA, visualization tools, optimization methods, multiuser interfaces, collaborative environments, or group decision rooms. User-friendly interfaces allow multiple users to provide input and generate real-time output to support negotiated spatial decisions. For example, value maps can be combined and transformed to support negotiated allocation of land use (e.g., Janssen et al., 2006; Recatalá and Zinck, 2008). Maps and MCA can also be combined to map and explore land use conflicts (e.g., Feick and Hall, 2002; Goosen et al., 2007). Optimization methods and maps have been integrated to support interactive land use allocation (Santé-Riveira et al., 2008), or to support interactive design rounds of land use plans (Janssen et al., 2008a). Moreover, maps can be integrated with real-time analysis and visualization tools into collaborative environments to support group decision-making. Examples of such environments include the 'digital workshop' to support community planning workshops (Salter et al., 2009), or the 'What if? ™' tool for collaborative scenario building (Klosterman, 1999). These decision environments feature tools to dynamically explore the spatial outcomes of planning alternatives and to quantify real-time changes in terms of indicators of relative suitability.

This section divided the use of maps according to a three-stage decision process. The majority of studies suggest that process-based support can be as meaningful as decision-based support, stressing that collaborative map-based decision support should integrate stage-specific tools that fulfill specific information requirements.

5.3. Research approach

5.3.1. Policy workshops

The present approach distinguishes three types of workshops: design, analysis and negotiation. The roles that maps play in each workshop are defined according to the framework on map use of Carton and Thissen (2009), which conceptualizes the collaborative use of maps in multi-actor planning processes (Table 5.1).

Table 5.1. Map use for policy workshops (adapted from Carton and Thissen, 2009).

Workshop	Map seen as	Map used for
Design	Design language	Communication
Analysis	Research model	Spatial evaluation
Negotiation	Decision agenda	Interactive decision support

Design and analysis workshops are found in the beginning and middle of a planning process and the negotiation workshop towards the end. The workshops are interconnected because the outcomes of the design workshop are used as input for the analysis workshop, whose outcomes are in turn used as input for the negotiation workshop. Each workshop is designed to address specific objectives and therefore requires tools that deal with the tasks needed to meet these objectives. Tasks and participants are also specific to each workshop.

A workshop typically follows this format: 1) introduction and goals; 2) available data and support tools; 3) Touch table assignment using tools; 4) presentation of results; and 5) plenary session and discussion. The workshop series can be compared to the Charrette System™, which involves multiple-day, collaborative sessions (or charrettes) for stakeholder consultation and group work for scenario planning and evaluation. In this system, groups of stakeholders work in sup-groups and make real-time use of information technology to produce feasible solutions to a planning problem (Lennertz and Lutzenhiser, 2006).

5.3.1.1. Design workshop: maps for communication

In a design workshop, maps are used as the means of communication to facilitate stakeholder dialogue. Communication is supported by a set of drawing tools with which stakeholders express opinions using maps. Stakeholders are invited to work together around the Touch table and share their views about land use issues of a study area using a set of digital maps as the only source of support information. Objectives of a design workshop are:

- To improve stakeholder understanding of the problem
- To prompt exchange of local knowledge and stakeholder dialogue
- To identify stakeholder objectives

Typical participants of a design workshop include representatives of stakeholder groups.

5.3.1.2. Analysis workshop: maps for spatial evaluation

In an analysis workshop stakeholders work together on the Touch table and use spatial tools collectively to assess, compare and rank a set of land use alternatives. Objectives of an analysis workshop are:

- To communicate information about land use suitability
- To generate expert feedback about suitability maps
- To assess the performance of potential land use plans for an area

Participants of an analysis workshop generally include scientists, researchers and experts in disciplines relevant for the study area. This group of experts should be in charge of making a set of maps that are relevant to the evaluation framework defined previously in a design workshop

5.3.1.3. Negotiation workshop: maps for interactive decision support

In a negotiation workshop, stakeholders are invited to work together on the Touch table and use tools to develop a land use plan. Objectives of a negotiation workshop are:

- To communicate information about the qualities of the plans to stakeholders
- To use this information to improve the quality of the plans
- To negotiate a land use plan that is perceived as acceptable by all participants

Suitable participants of a negotiation workshop are principally decision- and policy-makers and representatives of stakeholder groups.

5.3.2. The Touch table

The Touch table (Figure 5.3a) works as a common map interface to support multi-stakeholder dialogue and user-map interaction (see Section 2.3, for technical details of the Touch table). The rationale behind the choice of the Touch table for the workshops is threefold. First, it constitutes a support tool for face-to-face group collaboration and decision-making. Second, it allows users to work with computer-based tools, like the spatial tools of this approach, without having a computer get in the way. Third, it provides a shared map interface that incorporates the well-known capabilities of GIS for navigation, map structuring and visualization, which can significantly complement large-format printed maps.

5.3.3. Spatial tools

Three types of spatial tools were developed to support each type of workshop: drawing tools, evaluation tools and negotiation tools. All tools were developed within the ArcGIS environment and used the Touch table as their interface. The evaluation and negotiation tools were developed using CommunityViz Scenario 360™, an ArcGIS extension for interactive spatial planning. This extension was developed by Placeways LLC in partnership with the Orton Family Foundation and is available for purchase at http://placeways.com/communityviz/. The extension has been used in previous studies on visualization techniques for participatory planning workshops (e.g., Salter et al., 2009).

5.3.3.1. Drawing tools for design workshops

The design workshop involves two drawing tools. With the first tool, stakeholders can add elements to an underlying map by drawing points, lines or areas. With the second tool, users can provide comments or feedback by drawing color-coded lines on top of a background map. Both tools allow simultaneous drawing by multiple stakeholders, distinguishing each stakeholder by a color and storing each input in a separate layer. The drawing tools were created using DT Collaborate ™, a plug-in for ArcGIS that enables simultaneous multi-touch, identifying who draws what when used in conjunction with the Touch table. The plug-in was developed by Circle Twelve and is available for purchase at http://www.circletwelve.com/. Using ArcGIS on the Touch table allows users to combine multiple maps on request by using transparencies, toggling layers on and off, or by swiping the topmost layer.

5.3.3.2. Evaluation tools for analysis workshops

These tools utilize spatial MCA for assessment and comparison of land use plans (see Chapter 2). Spatial MCA is used to combine criterion maps into objective maps and finally into a total value map for an alternative. Figure 5.2 illustrates the path followed to obtain a total value map for an alternative a_n. Criterion value maps are combined using spatial MCA to obtain objective value maps, which are in turn combined to obtain a total value map for that alternative. Lastly, using spatial aggregation, a total value map is transformed into an aggregated score, the total value of an alternative a_n, which allows for ranking of more than one alternatives. The same procedure is followed to obtain a total value for a criterion map or an objective map (see circles on the right portion of Figure 5.2).

The multicriteria method used in this study is generally known as weighted summation, in which criterion scores are transformed into values or utility scores. Objective and total values are calculated as the weighted sums of these standardized scores (See equations (5.1) and (5.2)). The advantage of this method is that it is transparent and the interpretation of the weights as trade-offs is relatively easy to understand (Belton and Stewart, 2002).

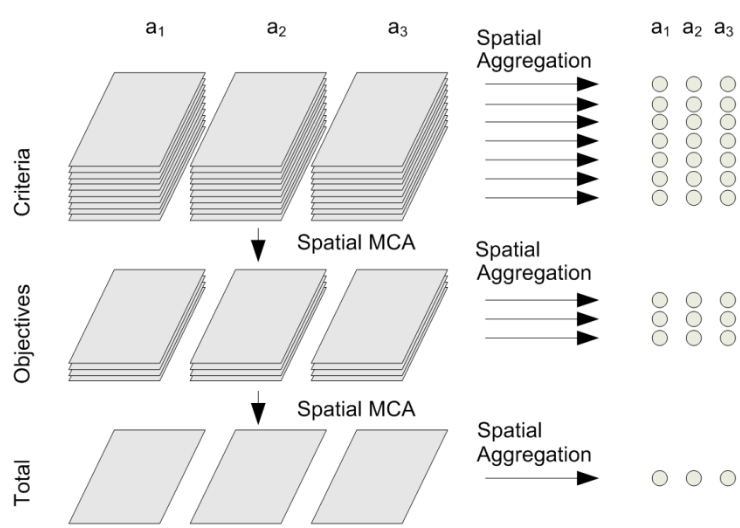


Figure 5.2. Steps in spatial evaluation, adapted from Herwijnen en Rietveld (1999).

Expert judgment is used to transform attribute maps into standardized maps that can be transformed into maps representing objective values and total value. A map showing standardized attribute values is referred to as a value map. An aggregated score for one criterion is calculated as the area-weighted average of the criterion values of all spatial units. Equation (5.1) shows the calculation of the spatially aggregated value *s* of objective *j* and for all *m* polygons in a land use alternative; r_{mj} is the value of objective *j* for polygon *m*, and standardized on the area of polygon *m*:

$$s_j = \sum_{m=1}^{M} r_{mj} \tag{5.1}$$

Where objective value r_{mj} is calculated using Equation (5.2) as the weighted summation of the values *v* of all *k* criteria that are linked to objective *j*, for polygon *m*:

$$r_{mj} = \sum_{k=1}^{K} w_{jk} \cdot v_{mjk} \tag{5.2}$$

The same procedure is followed for each specific objective in order to calculate the total value for polygon *m* as the weighted summation of the values *s* of all *j* objectives, and then the spatially aggregated total value for an alternative a_n.

5.3.3.3. Negotiation tools

These tools support negotiation on land use allocation. The tools extend spatial MCA for analysis with negotiation support and include dynamic plan evaluation tools, tools for identifying spatial trade-offs between objectives and allocation tools to change land uses on the map on the Touch table (see Chapter 3). The dynamic evaluation tools provide feedback on the land use changes negotiated and implemented by the participants by recalculating aggregated values for each objective and total.

The trade-off identification tool utilizes information on objectives and parcel area sizes to indicate which sections of the polder are potentially suitable for a favorable exchange between two or more land use types. Equation (5.3) shows how a trade-off set of parcels is selected based on cumulative parcel area sizes and objective scores. A detailed description of the formalized definitions utilized in the tool can be found in Arciniegas et al. (2011). A trade-off set *T* is a subset of the whole parcel set *P* and contains all parcels represented by polygons that are favorable for a swap between a pair of land-use types, such that high-value and low-value polygons for one land use type overlap low-value and high-value polygons, respectively, of a second land use. Let *a* and *b* be any two land-use types from the set of *L* land use types. Hence, $T \subseteq P$, $a \in L$, $b \in L$ and $a \neq b$. For land use type *a*, the high-value polygons are in subset G_a and the low-value polygons are in subset B_a. For land use type *b*, the high-value polygons are in subset G_b and the low-value polygons are in subset B_b. The overlap between high-value polygons for objective *a* and low-value polygons for objective *b* is defined as $G_a \cap B_b$. The overlap between high-value polygons for objective *b* and low-value polygons for objective *a* is the opposite case: $G_b \cap B_a$. Hence, the trade-off set (for land use *a*, land use *b*) is the union of both sets:

$$T_{ab} = (G_a \cap B_b) \cup (G_b \cap B_a) \tag{5.3}$$

A similar procedure is followed for more than one land-use type.

5.4. Results: design workshop

The three workshops were part of the land use planning process for the Bodegraven polder. As a consequence of the current land use issues in the polder, the provincial authorities have started a process to adapt land use in the polder in cooperation with all stakeholders. Chapter 2, Section 2.3, has provided a detailed description of the study area, its current land use issues and the resulting planning process.

Participants in the design workshop included ten stakeholders representing the province of South-Holland, the municipality of Bodegraven, the water management authority and a nature non-governmental organization. A detailed report of the workshop can be found in Cornelisse et al. (2007a). At the start of the workshop, a set of topographic and thematic maps of the polder were presented to the stakeholders. The most important maps presented were: high-resolution aerial photography, Digital Elevation Model (DEM), current and historical topographical map, configuration of polder units, soil type, estimates of both future water levels and ground subsidence. Then, some time was allowed for familiarization with the Touch table technology and the drawing tools. Next, the participants were divided into two groups, which worked in two parallel sessions: one group working on the Touch table and the other on paper maps (Figure 5.3).

The second part comprised two drawing assignments, each involving a different drawing tool. As the region is a popular destination for recreational cyclists, the first assignment consisted of drawing bicycle tracks across the study area. The participants were asked to propose new tracks by drawing lines on a map of the area. Any map from the available set could be requested to be used as the drawing background. During this drawing session, several maps were requested by the participants to support their drawings. The ‘nature organizations’ requested low-detail maps (scale 1:50000) showing ecosystem types for the whole area. The ‘municipalities’ used detailed maps to support drawing the tracks: the aerial photography (resolution 50 cm x 50 cm) was used to identify landmarks and dikes and connect them with the tracks. The high-resolution DEM (5 m x 5 m) was also requested but did not prove as useful as elevation for the polder ranges only between -1 and -2 meters above sea level. The ‘water board’ stakeholder requested maps of their water management constructions because they planned to use the cycle track for their maintenance vehicles. As a result, many of the drawn tracks run alongside constructions or water ways (Figure 5.4). Other popular maps included the current and historical topographical map (both 1:25000, resolution 2.5 m x 2.5 m) and the location of dikes. Although the construction of a cycle track in the area was unlikely, this assignment was important for the workshop because it allowed participants to become familiar with the interactive maps and to communicate their knowledge on the area using these maps. Since constructing cycle tracks was considered unrealistic, the choices made in this exercise were not perceived to affect the interests of the stakeholders involved. This made this exercise function as a useful warming up for the workshop.

(a) (b)

Figure 5.3. Stakeholders working on: (a) the Touch table and (b) printed maps.

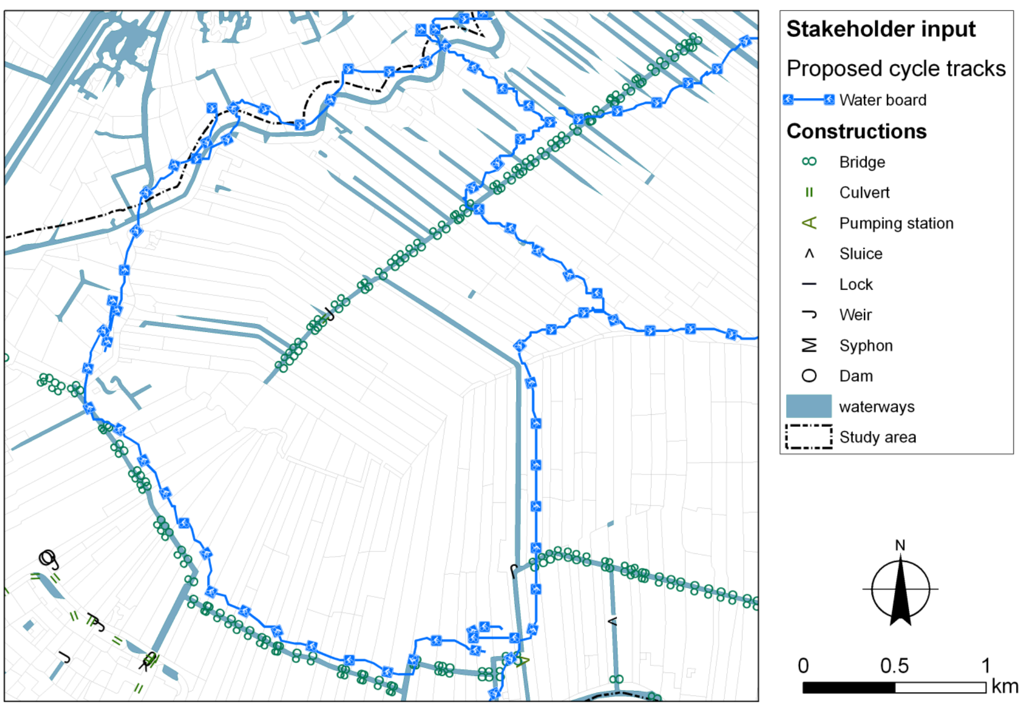


Figure 5.4. Proposed cycle tracks drawn on the Touch table and combined with a map of waterways and constructions.

The second assignment involved the evaluation of land use scenarios for the area. Land use for a peat-meadow polder is driven by water tables. Three possible types of land use were identified: intensive agriculture, extensive agriculture and nature (see Section 2.4.1 for a description of each land use type). The assignment began with a presentation of three land use plans, each with corresponding estimates of water levels and ground subsidence. One group of participants was asked to evaluate each plan by drawing positive and negative aspects of the plan on the Touch table map, while the other group was asked to do the same using printed versions of the plans. Within a group, three stakeholders were asked to indicate with solid lines those parts of the plan they considered to be positive. Dashed lines were used for parts deemed negative. In order to distinguish between the three stakeholders, each stakeholder was given his/her own color. Figure 5.5 shows one of the land use maps overlaid with the feedback from one group drawn on the Touch table.

Next, each stakeholder presented the maps generated in each assignment. Discussion around the Touch table showed that different stakeholders used different maps. For example, in providing feedback, the stakeholder ‘province’ made extensive use of two maps: estimated water levels and ground subsidence (both raster maps, resolution 25 m x 25 m). Figure 5.6 shows the two maps overlaid with the feedback provided by this stakeholder. Solid and dashed lines indicate positive and negative aspects of the plan, respectively. Figure 5.6a shows that areas with high water levels (from -30 cm and above) were marked as important (positive) aspects of the plan due to their suitability to nature conservation. Land use ‘nature’ is suggested for these areas and marked as ‘green’. Figure 5.6b shows that areas with the highest probability for ground subsidence (from 0.8 cm/year and above) were considered to be negative aspects of the plan if intensive agriculture prevails. The main reason was that the practice of intensive agriculture would not be sustainable in sinking grounds. Extensive agriculture (indicated as ‘yellow’) was recommended for these areas as this contributes less to subsidence.

The last part of the workshop involved the evaluation of three land use scenarios using standard MCA. In a plenary session, a number of relevant criteria were introduced and explained to the participants. These criteria were grouped into four categories: 1) profitability of agriculture; 2) minimization of land subsidence; 3) maximization of the visual quality of the landscape; and 4) maximization of the natural value of the area. The participants were asked to assign a score between 1 and 4 (with 4 being the best alternative) to each plan for each criterion. A ranking of the three base plans constituted the result of the MCA. Having the participants assign tentative scores for each alternative using these criteria and then using these scores to rank the three alternatives with MCA was a good test on completeness and relevance of the criteria used. These rankings were used to define a final set of criteria that would be used in ensuing workshops. This part of the workshop was supported with DEFINITE, an MCA software package (Janssen and Herwijnen, 2007).

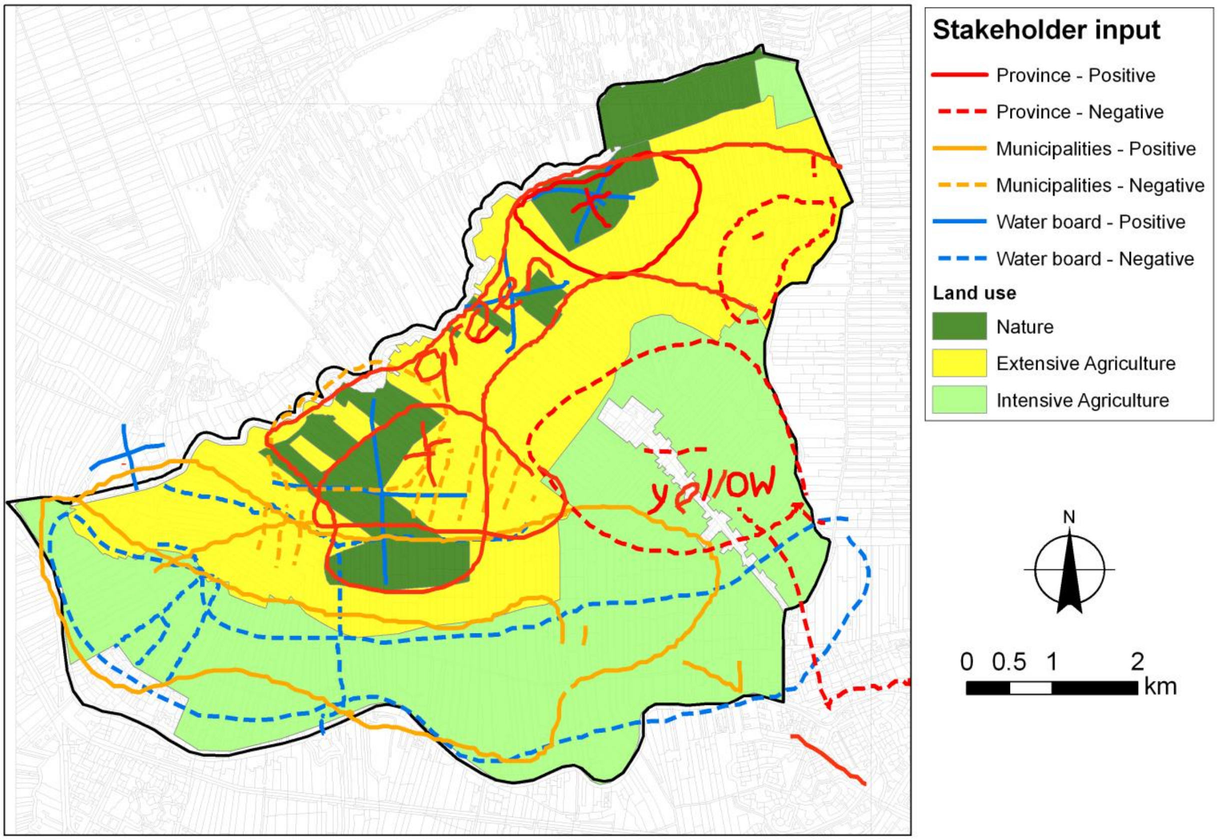
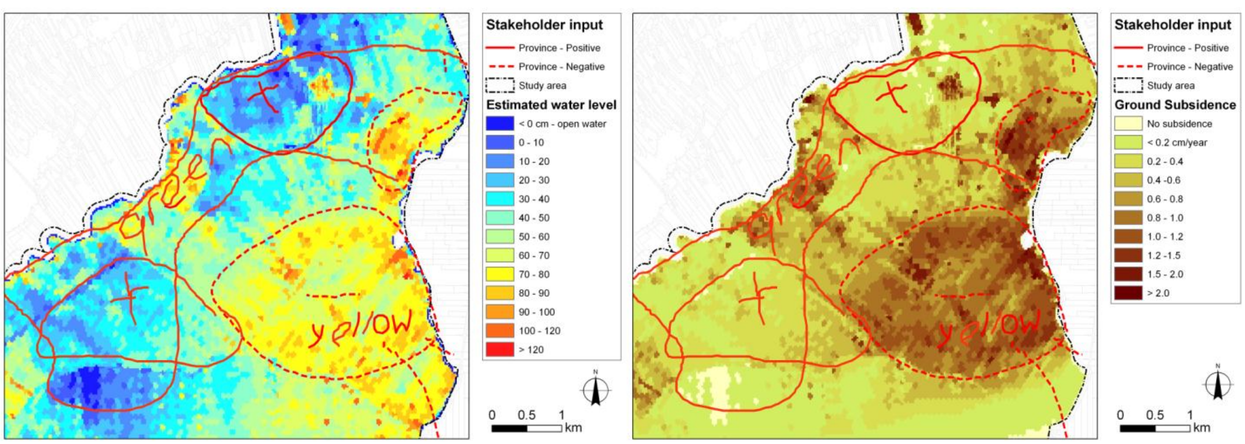


Figure 5.5. Map showing input from three different stakeholders drawn on the Touch Table.



(a) **(b)**

Figure 5. 6. Stakeholder input drawn on the Touch table combined with: (a) the water level map and (b) the ground subsidence map.

Effectiveness of tools

To get an impression of the effectiveness of the communication support offered, a survey was conducted among all participants at the end of the workshop. Participants were asked to rate their experience and express their preference between the Touch table and printed maps by specifying one level of satisfaction for a specific aspect using a 5-level Likert scale. The survey was completed by all participants, 70% of whom preferred the Touch table over printed maps. 80% thought that the Touch table has an added value for this type of workshops with respect to printed maps, because of the possibilities to easily choose, combine and consult maps at different levels of detail. 80% thought that the Touch table helped increasing their awareness of new aspects of the region's problems and different standpoints as well as scopes of other stakeholders. In general, participants found the workshops both useful and enjoyable. They also indicated that the workshop tools were effective for communicating large amounts of information in a short time. Working with the information prompted input from all participants and stimulated discussions about problems of the area and possible solutions. Participants agreed that this approach could also be used with policy-makers as well as with local farmers and other residents in the area.

5.5. Results: analysis workshop

An analysis workshop was held with fifteen experts from a range of disciplines involved in peat-meadow research for the polder. Disciplines included agronomy, soil science, hydrology, climate change and greenhouse gas emissions, landscape architecture and planning and landscape ecology; see Cornelisse et al. (2007b) for a full workshop report. In the first part of the workshop, results from the previous design workshop were outlined to the participants. This included the criteria framework for plan evaluation and the alternative land use plans together with their qualitative assessments. In the second part, the experts were asked to present suitability maps for each plan, followed by a discussion about how each map can be linked to each criterion. Relevant attribute maps presented at the start of the workshop included:

- Suitability map for agricultural land use (raster, 25 m x 25 m)
- Total greenhouse gas emissions for each land use type (vector, 1:50000)
- Mineralization and denitrification of the peat-meadow soil (vector, 1:50000)
- Spatial distribution of government subsidies for extensive agriculture (vector, 1:25000)
- Estimation of future groundwater tables for climate change scenarios (raster, 25 m x 25 m)
- Estimation of future ground subsidence due to mineralization and denitrification (raster, 25 m x 25 m)
- Suitability map for different natural ecosystems (raster, 25 m x 25 m)

The third part involved an assessment by experts of the relative qualities of different types of land use. Initial scores were based on published studies on the valuation of peat-meadows (e.g., Kleijn and Van Zuijlen, 2004) and presented in a 'value table'. Experts were asked to change scores on this table, where necessary, for each combination of land use and water level included. Table 5.2 shows a section of a value table with scores assigned by experts for objective 'agricultural production'. In several rounds, experts discussed scoring results (value maps) and reassessed land use-water level combinations. As soon as changes were made to the value table, value maps were updated and displayed on the Touch table in real time. A final value table constituted the result of this step.

Table 5.2. Value table for intensive agriculture.

Water level		Intensive Agriculture
	> 0	0
0	-10	0
-10	-20	3
-20	-30	5
-30	-40	6
-40	-50	7
-50	-60	8
-70	-80	8
-80	-90	7
-90	-100	6

The next step involved setting weights for criteria and objectives. This resulted in value maps for all objectives. Participants were able to explore in real time the link between weights and performance scores. After a number of rounds, the participants agreed on a weight of 50% for nature, 30% for ground subsidence, 10% for agriculture and 10% for landscape. Using these weights, it was possible to generate total value maps for all alternatives: the reference (current) land use situation of the polder and the three alternative land use plans presented during the design workshop and based on estimates of water levels and ground subsidence (Figure 5.7). By visual comparison of the four maps, land use alternative 1 appears to perform best. The reference situation clearly performs worst and the performances of alternatives 2 and 3 cannot be distinguished easily.

Numerical results of this step were available on a separate screen. Figure 5.8 shows aggregated results for the four land use plans. The values for the four objectives and the total values were calculated using Equations (5.1) and (5.2). Rankings show that the reference situation performs best for ‘Agriculture’. Alternative 1 performs best overall and also for objectives ‘Landscape’ and ‘Nature’. Alternative 3 presents the best performance for ‘subsidence’. In the fourth part of the workshop, final evaluation results were presented by the participants, followed by a discussion on the credibility and robustness of these results. The workshop ended when all experts agreed on the standardization rules and a set of criterion and objective weights. A final version of the value table and a set of criterion and objective weights constituted the main product of the workshop, together with all value maps and final rankings.

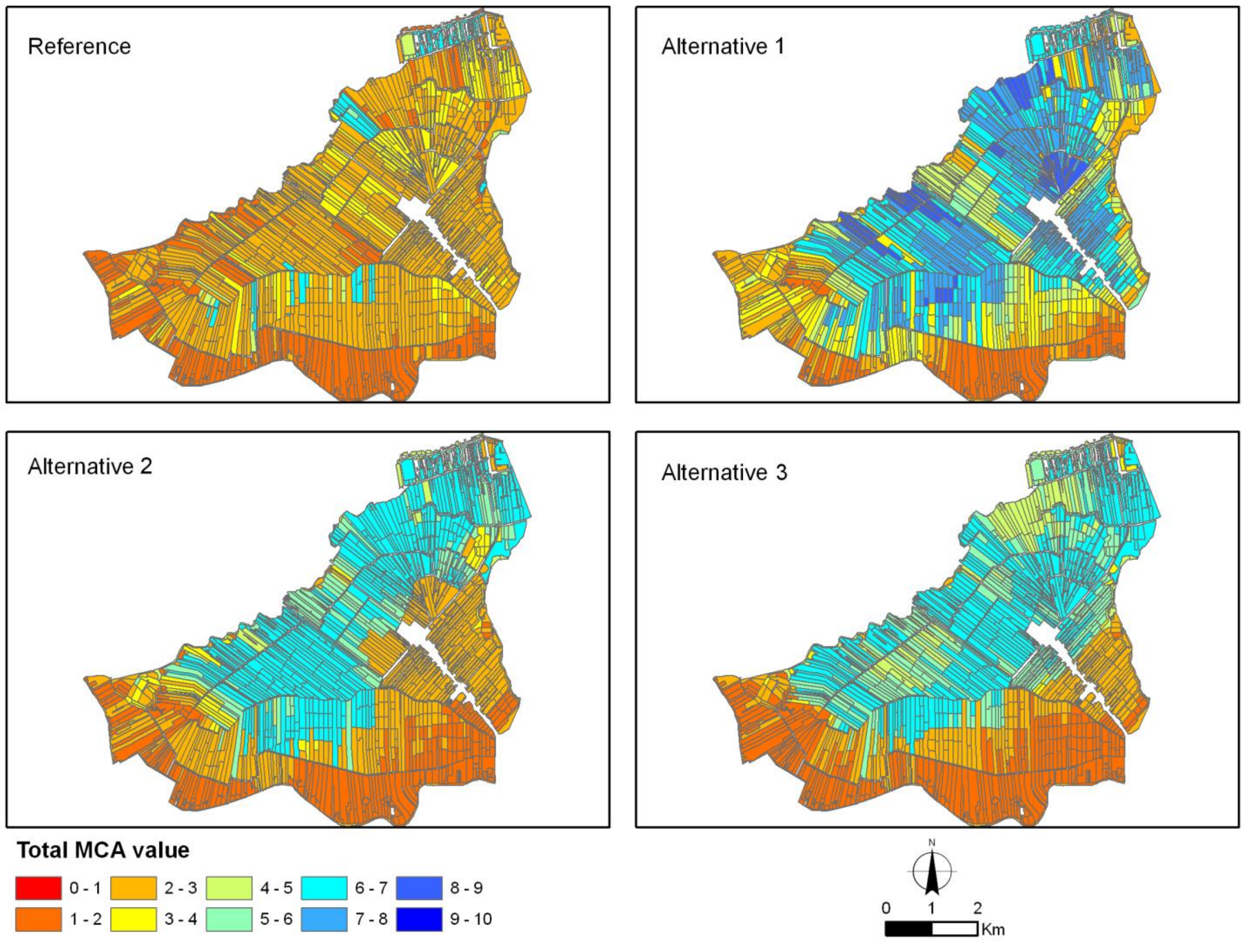


Figure 5.7. Spatial evaluation of land use alternatives.

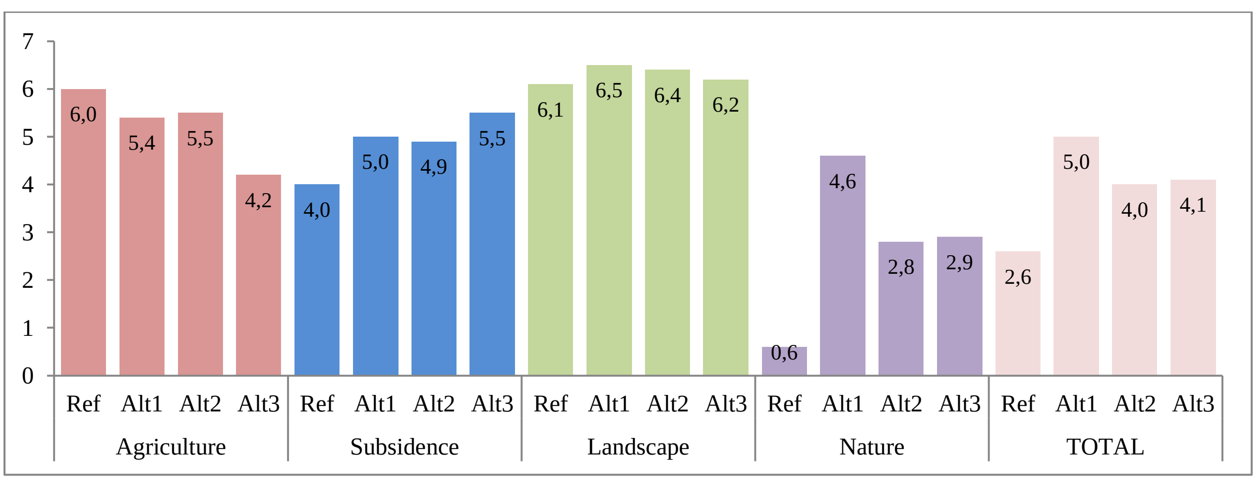


Figure 5.8. Numerical assessment of land use alternatives.

Effectiveness of tools

The post-workshop survey conducted among all participants showed that 66% of them considered the aggregated scores to be easy to use and 56% to be useful. 90% of the participants found the Touch table workshop setting to have an added value for spatial evaluation, namely the possibility to quickly see the spatial and numerical consequences of changing variables, such as value table scores and weights. Moreover, as participants of this workshop were mainly researchers, they asked for background maps and underlying assumptions of the value maps produced. The possibility to quickly move through the underlying material increased the credibility of the information presented. The results presented were also used to identify missing information.

5.6. Results: negotiation workshop

A negotiation workshop was held with eight participants, which included provincial authorities and experts; see Janssen et al. (2008) for a full workshop report. The workshop began with a presentation of the reference land use map for the polder, together with its corresponding set of objective value maps and aggregated scores. Then, the participants were divided into two groups and asked to carry out a land use allocation assignment on the Touch table. The goal of the assignment for both groups was to modify the reference land use situation into a consensus land use plan that maximizes stakeholder values while meeting certain area size goals. Both groups worked on the assignment simultaneously on two separate Touch tables in two parallel 90-minute negotiation sessions. Each participant of a group was asked to play a stakeholder role from the three possible roles (farmers' organizations, agricultural nature organizations, nature organizations) and increase the quality of a specific objective (agriculture, landscape, nature, respectively). The goals were to allocate 860 ha of nature, 1600 ha of extensive agriculture and 1600 ha intensive agriculture, and to increase the qualities of the four objectives and the total quality of the reference plan. Area goals were defined according to the project goals set by the provincial authorities. Experiments prior to the workshop had shown that the assignment needs to be framed in such a way that there is room for improvement for all stakeholders.

Upon completion of the parallel sessions, each group was asked to present their final plan and to explain their negotiation and allocation strategy. Both groups used different negotiation strategies. Participants of the first group agreed to create a nature corridor by connecting two existing nature areas and to allocate extensive agriculture around the corridor. Figure 5.9 illustrates how the decision support tool was used by this group: at the start of the assignment, they decided to search for areas with a high value for extensive agriculture. They then used the trade-off tool to display this information on top of the parcels (Figure 5.9a). Next, they proceeded to allocate extensive agriculture on areas with high value for extensive agriculture and low value for the existing land use, i.e., intensive agriculture (Figure 9b). Finally, they completed the corridor by allocating land use nature to parcels with a high value for nature and low for extensive and intensive agriculture (Figure 5.9c).

Aggregated results were provided to both groups as bar charts on a separate screen. Figure 5.10 shows the evaluation results for the start situation, intermediate step and final plan, as achieved by the first group. Figure 5.10 shows that the group managed to improve the reference plan for each objective and in total. Despite using a different negotiation strategy, the second group achieved almost identical aggregated values as the first group. Their strategy consisted of creating two nature corridors (instead of one) to connect an existing patch of nature of the reference plan with a water body situated on higher ground, west of the polder.

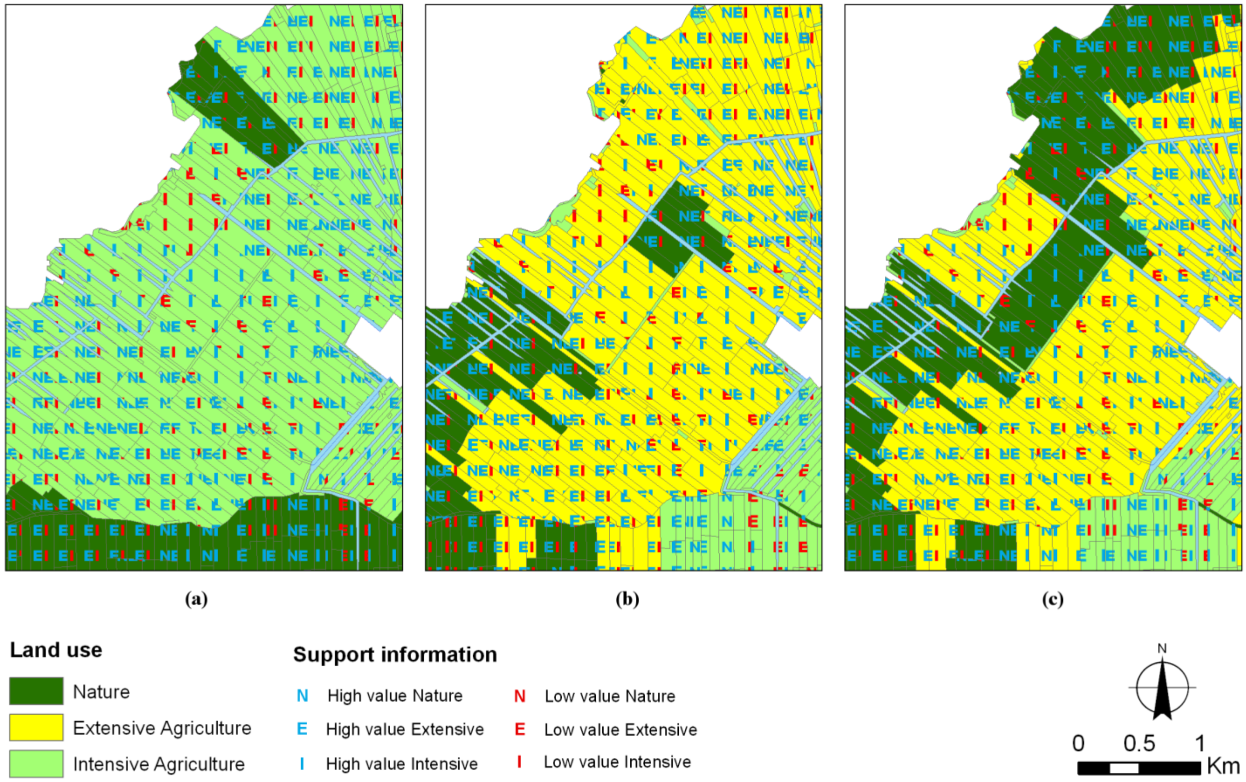


Figure 5.9. Negotiation support for: (a) the start, (b) intermediate step and (c) end of assignment.

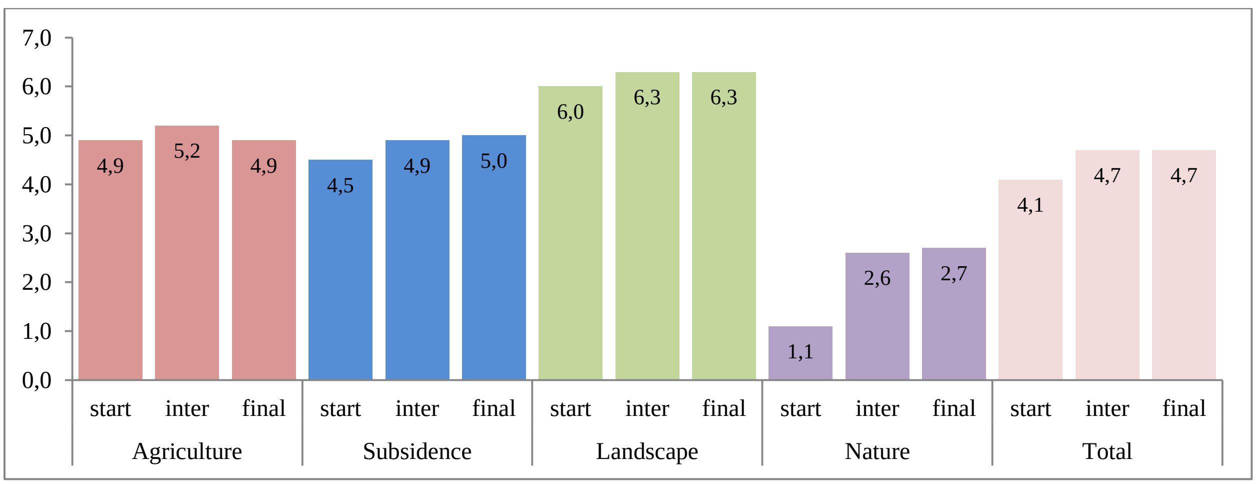


Figure 5.10. Objective and total values for start, intermediate and end of the assignment.

Effectiveness of tools

At the end of the workshop, all participants completed a questionnaire about the usefulness of the support provided using a 5-level Likert scale. Concerning the information on plan qualities, 56% of the participants considered the aggregated MCA scores for objectives and overall to be useful or very useful and 66 % considered these scores to be easy to use. Particularly, this information was considered to be credible enough to be used for negotiated allocation. The value maps presented at the beginning were also deemed relevant for the negotiation. The interactive decision support was considered to be useful by 73% of all participants, mainly because of its ease of use and the fact that it increased involvement and divided responsibilities fairly. Although the two resulting plans showed different spatial distributions of land use, both groups achieved almost the same increase in quality for each objective. Although both groups used different strategies, the total value of the plan was almost the same for both groups.

Despite their positive feedback, the participants questioned the assignment provided and argued that in real life the assignment would look different. They also argued that the setup of the assignment pushed them in a certain direction. The participants agreed that the support offered made it easier to identify opportunities and was useful to support institutional stakeholders. They questioned, however, whether it would also work for local stakeholders, such as farmers or residents. The institutional stakeholders expected that the local stakeholders would be more defensive resisting change and would challenge the setup of the assignment and the underlying assumptions. To support this type of group, a lot more detailed information would be needed.

5.7. Conclusions

This article demonstrated the use of spatial decision support in three types of workshops held at different points of the land use planning process of a Dutch peat-meadow polder, and addressed the following research question: *how can spatial decision support tools meet the requirements of a collaborative land use planning workshop?*

5.7.1. Spatial decision support

Previous studies have stressed that presenting spatial information through interactive map interfaces during planning workshops facilitated exchange of views on spatial decision problems (e.g., Andrienko et al., 2007; Bacic et al., 2006). To achieve this, the decision support provided in the design workshop combined maps, simple drawing tools, basic GIS functions and a shared map interface in the Touch table to support communication of spatial information and knowledge transfer. Maps were used to acquire drawn input from participants, which was then structured as GIS layers. The Touch table made it possible to share and confront views of different participants on various land use issues. Indeed, participants reported an increased understanding of spatial aspects of the decision problem and a raised awareness of the different scopes relevant to other participants, highlighting scale and level of detail as important aspects of the backgrounds maps. Participants found it easy to interact with the table. Sitting around the table created an atmosphere of a joint effort and stimulated therefore cooperation.

According to earlier studies, MCA was not used as a stand-alone tool but was used as a component of a more integrated system (Goosen et al., 2007; Jankowski et al., 2001). The spatial evaluation support offered in the analysis workshop allowed the integration of multi-disciplinary expertise for assessing and ranking potential land use alternatives. The Touch table facilitated discussions about the assessment of criteria scores and supported simultaneous visualization of multiple value maps. Providing information on quality in real time played a central role in fostering an immediate exchange of feedback between participants. The information offered should be specific to the task and the amount of information provided should be limited and well structured. If too much information is presented, participants will ignore this information even if it is relevant to the task.

Recent studies have argued that MCA-based tools can provide useful support during spatial negotiations in early phases of collaborative planning (e.g., Goosen et al., 2007; Recatalá and Zinck, 2008). The MCA-based tools utilized during the negotiation workshop supported the collective generation of consensus land use plans that improved on a reference situation. Providing information on trade-offs between evaluation objectives directly on parcels on the map facilitated the negotiation process that led to reaching agreements for the reallocation of land uses to parcels. The post-workshop survey showed that trade-off information was used more extensively than the aggregated scores. As a general rule, tools should be designed both as intuitive and simple as possible.

5.7.2. Lessons and limitations

Organizing policy workshops is a learning process that requires substantial effort in terms of preparation, logistics and technical challenges. An important lesson learned is that preparation is crucial. A good start is to write a detailed script, which includes the objectives and time table of the workshop and the intended results of the various assignments. In addition, the script includes all maps to be prepared and the specifications of the applications to be used. The applications should be well tested in advance since there is little tolerance from the participants for technical or methodological problems. To test if the assignments lead to the intended results, it is essential to conduct a dry run of the workshop. During the workshop at least two people should assist the participants: one to provide support in the use of the application itself and another one to support the discussion. Although participants can add notes to their actions, usually only the actions are recorded. As the participants usually make relevant remarks during the assignments, it is recommended to have a video camera record the workshop or to appoint somebody to take detailed notes of all actions.

A second lesson is that, even if the workshop fits well into a policy process, it is not always easy to convince policy-makers to include the workshops in the planning process. There is fear for the unknown and fear that bringing the problem outside the usual setting would change the level of control on the process. Careful consideration should be given to the mix of participants to be invited. To convince participants to join the workshop, the objectives should be made clear at the start as well as the composition of the group. It is therefore important to ensure that there is something in it for all the participants invited and that the workshop is a pleasant experience. The main plus of the present approach is to get different types of people talking so that opportunities for exchange between different sources, or types, of local and expert knowledge can be combined (see also Robinson et al., 2006).

The present approach has four limitations. First, a successful implementation of a workshop-based approach depends highly on the local planning situation, political traditions and laws, and a cooperative attitude by participants. For a Dutch polder, the workshops were successful because of the Dutch way of decision-making but in other parts of the world, in situations of sharp conflict or in a more power-based style of decision, it is questionable whether the approach would be as useful. Second, holding workshops with real stakeholders generally involves a low participant number, which makes it difficult to perform meaningful statistical analyses. Although the participants considered all workshops to be useful, more research should be conducted to assess spatial decision support of this nature using objective measurements of effectiveness and suitability (e.g., Arciniegas et al., 2012; Salter et al., 2009). Empirical studies with larger control groups are recommended to support real-stakeholder implementations. Third, participants may not want to fit the frame of the assignments or be open to new technologies, and hence may not participate. Fourth, the Touch table recognizes a maximum of four users working on it, which can restrict the amount of participants that can collaborate. Distributed approaches (e.g., Boroushaki and Malczewski, 2010) can be an alternative to include a larger number of stakeholders. Multiple Touch table sessions could be interconnected via a server computer of a computer network or through the internet. Future studies should also address the implementation of landscape visualization in policy workshops (e.g., Pettit et al., 2011; Sharma et al., 2011), especially at decision stages where future landscape scenarios are explored.

5.7.3. Conclusion

For all three workshops, the Touch table proved to be a useful instrument for facilitating group work around spatial information. Format and level of detail of the spatial information supplied in the tools were important aspects that needed to suit each workshop. Using maps on the Touch table as tools for communication, spatial evaluation and interactive negotiation appeared to be an effective method to support planning meetings with stakeholders with different backgrounds.

So far, this thesis has discussed three types of support tools and their implementation in three different types of planning workshops and corresponding application to a land use planning process. The next chapter describes the application of the methodology of this thesis to a marine spatial planning process. The chapter describes the use of the support tools in two consecutive stakeholder workshops of the spatial allocation process of tidal energy devices off the Mull of Kintyre, Scotland.

Chapter 6

Decision support tools for collaborative marine spatial planning: identifying potential sites for tidal energy devices around the Mull of Kintyre, Scotland

Abstract

Coastal areas worldwide are typically densely populated and moreover committed to a variety of uses. The further expansion of offshore activity, such as wind/wave/tidal energy, is likely to lead to conflict and hence opposition to these developments. This study details a novel approach to assess the potential for and resolution of such contention. Two stakeholder workshops were conducted in an area with high conflict potential due to offshore renewable energy development. In the workshops, stakeholders were invited to work together and carry out planning tasks using spatial decision support tools implemented in an interactive mapping device called the Touch table. The first workshop focused on the mapping of the values of the stakeholders involved; the second workshop on identifying the best compromise locations for the tidal devices. To support these workshops, two types of spatial decision support tools that were developed to support a terrestrial land use planning process in the Netherlands were adapted to suit the current problem. The value mapping tool combines regional attributes with local knowledge to form stakeholder value maps. The negotiation support tool uses these value maps to support stakeholders in finding the optimal location for tidal energy devices within the proposed energy site. Although participants had little or no experience with this method of decision support, they engaged easily with the process and were satisfied with the workshop results. This approach, which originated in a terrestrial setting, should ideally also be used in the rapidly developing context of marine spatial planning.

Focus: this chapter describes the design and implementation of the tools developed for this research, which involve GIS, MCA and the Touch table, in a series of workshops with stakeholders of the sea-use allocation process off the Mull of Kintyre, Scotland.

Research highlights:

- An approach developed for land use planning successfully resolved a marine spatial planning problem.
- Interactive value mapping addressed deficiencies in data and created credibility for value maps.
- Stakeholders with little experience in spatial decision support actively engaged with the spatial planning process.

This chapter is based on two articles:

Janssen, R., Arciniegas, G.A., Alexander, K.A. Decision support for collaborative marine spatial planning: identifying potential sites for tidal energy devices around the mull of Kintyre, Scotland. Submitted to Regional Environmental Change.

Alexander, K.A., Janssen, R., Arciniegas, G.A., O'Higgins, T.G., Eikelboom, T., Wilding, T.A., 2012. Interactive Marine Spatial Planning: Siting tidal energy arrays around the Mull of Kintyre. PLos ONE, 7(1): e30031. doi: 10.1371/journal.pone.0030031.

6.1. Introduction

Increasing pressure on the use of the marine environment has meant that marine spatial planning has gained momentum to deal with competing activities such as fisheries, shipping, marine parks, wind farms or tidal energy generation (Douvere and Ehler, 2009). Marine spatial planning (MSP) is an emerging responsibility of resource managers. An advantage of MSP is that it makes tradeoffs in resource use and sector (stakeholder group) values explicit, but doing so requires tools to assess trade-offs (White, et al., 2012). This article demonstrates that tools developed in a terrestrial setting can be applied to support the MSP process.

MSP is a way of improving decision-making and delivering an ecosystem-based approach to managing human activities in the marine environment (European Union, 2008). It is a planning process which enables integrated, forward-looking, and consistent decision-making on the human uses of the sea. Spatial management in the marine environment aims to provide a mechanism to achieve consensus among all sectors operating in a particular area (Pomeroy and Douvere, 2008). Although there are many parallels between MSP and terrestrial planning, it is important to note that the two systems operate in very different contexts which will always limit the transferability of the experience of terrestrial planning to the sea. The sea can be viewed as a common resource and the seabed is usually owned by a single owner, such as the Crown Estate in the United Kingdom. This makes MSP very different from traditional land use planning with its highly differentiated pattern of property rights (e.g., Booth, 2003). Another key difference appears to be the core motivational aspects of setting up the two systems: the foundation of the British land use planning system was heavily focused on social and economic issues in the midst of the newly created welfare state, while the primary motivation for MSP has been ecological concerns and ‘better regulation’, and is therefore primarily underpinned by an ethical and epistemological basis that is derived from natural resource management, marine science and procedural efficiency (Ritchie and Ellis, 2010). Despite the similarities with land use planning, working in the marine environment poses unique problems. Firstly, offshore activities have traditionally been controlled by a central government where space is allocated within individual economic sectors rather than integrated between sectors (Curtin and Prelezzo, 2010). This results in a lack of relevant multidisciplinary expertise. Secondly, spatial and value data are often not quantified or are unquantifiable, or are of inadequate spatial resolution to implement informed planning. Thirdly, public recognition of the tight coupling between ecological, economic and social systems is not widespread. There is therefore a need to build capacity to understand and participate in the planning process (Alexander et al., 2012).

Spatial planning workshops use maps as the means of communication in combination with support tools that focus on visualizing, structuring and evaluating the spatial information presented in these maps. The integration of spatial information stored in a Geographical Information System (GIS) with decision support tools is commonly referred to as Spatial Decision Support Systems (SDSS). According to Malczewski (1999), an SDSS is a “computer-based set of tools designed for supporting a user or group of users in achieving higher effectiveness of decision-making while solving a semi-structured spatial problem”. As a result from a shift from a technocratic to more participatory approach to spatial planning the emphasis of SDSS has moved to a more group-based approach creating a need for collaborative tools. Collaborative SDSS integrate geographic information science with methods developed as part of interactive group decision support (Balram and Dragicevic, 2006).

The potential for marine renewable energy extraction is becoming more important in many coastal areas. However, with much of the world's coastline already committed, renewable energy will be one more user of the marine space. Scotland has ambitious plans for the development of offshore wind farms and wave and tidal energy (http://www.scotland.gov.uk/Topics/marine/marineenergy last accessed in April, 2012). The Mull of Kintyre is a site identified by the Scottish Government for potential tidal energy extraction. Kintyre is a peninsula in south-west Argyll on the west coast of Scotland. The principal town is Campbeltown. The study site, off of the south-western tip of the Kintyre peninsula (Figure 6.1) is an area of proposed seabed lease offered by Marine Scotland and the Crown Estate (owners of the UK seabed) for tidal energy development. Diverse industries and activities operate within the site which may be affected by tidal energy development. In 2010, the announcement of the potential development of an offshore wind farm array at Machrihanish, in Kintyre, led to conflict within the community and between the community and the developers and to eventual abandonment of the project. For this reason, the Kintyre tidal energy lease site was chosen as the case study site for this research.

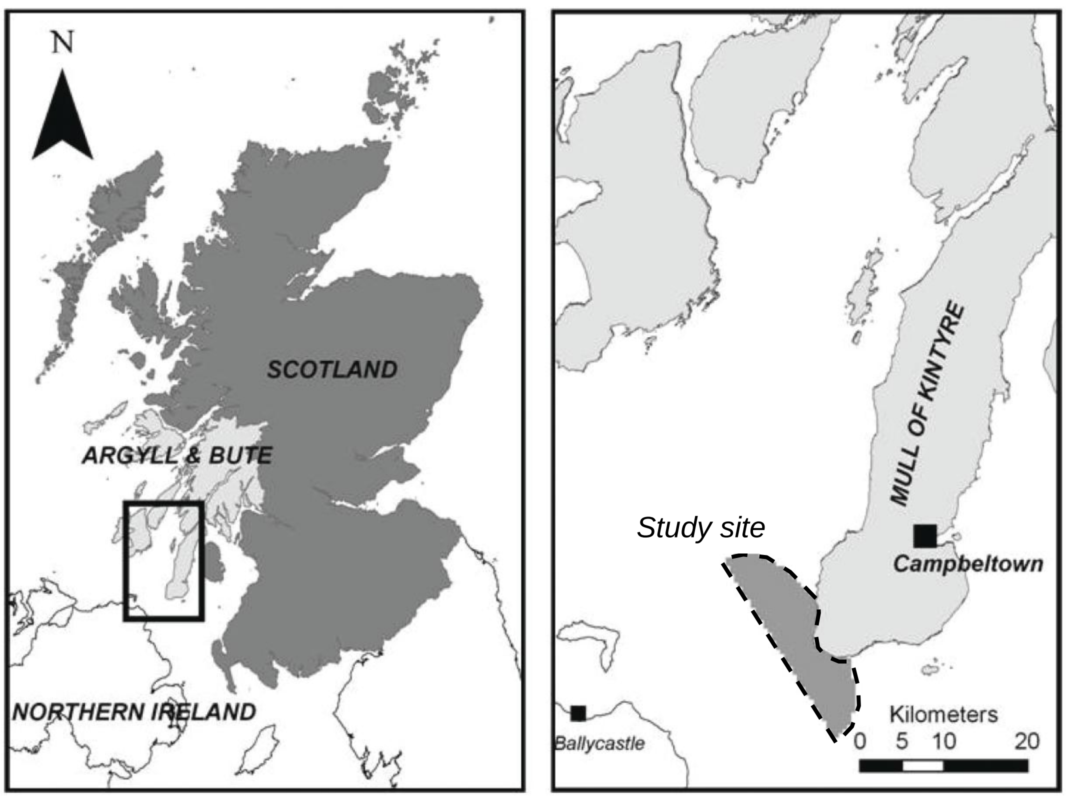


Figure 6.1. Location of the study site. Its outline was defined by Marine Scotland and the Crown Estate (owners of the UK seabed) for the purpose of tidal energy development.

Two workshops with local stakeholders were conducted in Campbeltown to identify suitable locations for the tidal energy devices. The first workshop focused on the mapping of the values of the stakeholders involved; the second workshop on the best compromise locations for the tidal energy devices. The interaction with the stakeholders in these workshops is described in Alexander et al. (2012). To support these workshops, spatial decision support tools that were developed to support a terrestrial land use planning process in the Netherlands (see Arciniegas et al., 2011; 2012) were adapted to suit the current problem.

This article describes how these tools were implemented to suit the specific characteristics of this marine planning problem and the results of the use of these tools in the stakeholder workshops. This leads to the following two research questions:

- Can simple drawing tools and spatial evaluation tools be used to integrate expert knowledge and concerns of local stakeholders for the evaluation of potential sites of tidal energy devices?
- Can spatial evaluation tools be used to support the identification of the best compromise solution for the location of tidal energy devices?

The remainder of this article is set up as follows. The next section describes the valuation support tool that was developed to map stakeholder values. The value maps are input into the negotiation support tool described in Section 6.3. The experiences with both tools in two stakeholder workshops are described in sections 6.4 and 6.5. In Section 6.6, conclusions are presented on the applicability and effectiveness of these tools.

6.2. Mapping stakeholder values

The decision support tools described in this article use methods developed within the field of spatial multicriteria analysis (MCA). Spatial MCA offers a range of methods to assess and compare decision alternatives on the basis of both local and expert knowledge (Malczewski, 2006). Aggregated and standardized indices and weighted suitability maps can integrate expert knowledge into participatory processes of natural resource assessment (e.g., Lesslie et al., 2008; Store, 2009). Spatial multicriteria methods have been used for mapping priority locations for sustainable land use planning (e.g., Strager and Rosenberger, 2006) or to map consensus between local stakeholders and outside experts (e.g., Chow and Sadler, 2010). Value functions have been used to mathematically represent expert judgment in order to assess standardized spatial indicators of landscape and ecological qualities (e.g., Beinat, 1997; Geneletti, 2005 or Orsi et al., 2011). Fuzzy methods (Jian and Eastman, 2000), particularly membership functions, have also formalized local knowledge and expert opinions (e.g., Ekmekçioğlu et al., 2010 or Chiou et al., 2005).

Two tools were developed for use in the stakeholder workshops: a value mapping tool and a negotiation support tool. The valuation support tool combines the attributes of the region with stakeholder input into value maps. The negotiation support tool uses these value maps to support the stakeholders in finding the optimal location for tidal energy devices. Participants interact with the tools using the Touch table (section 2.3). Participants touch the table with their fingers, e.g. to draw locations on a map as points, lines or areas and/or to change the land or sea use of locations within a study area. The tools use spatial MCA to process and a GIS to store and present this information. All tools were developed within the ESRI Arc Map 9.3 environment and employed the Touch table as their interface. The drawing tools were developed within the Arc Map-embedded Visual Basic for Applications environment. The scoring tools were developed using CommunityViz Scenario 360™ (http://placeways.com/communityviz/ last accessed in April, 2012), an ArcMap extension for interactive spatial planning.

The objective of using the valuation support tool is to generate a value map for each stakeholder. In this study, a value map is a raster map of the study area where the value of each cell represents the value of that cell to that stakeholder. The specific value of each cell in the study area is a standardized value in a predefined range. The valuation tool is used in four steps (Figure 6.2):

1. Collection of attribute map layers
2. Valuation of these map layers
3. Aggregation of map layers into a stakeholder value map
4. Validation and correction of the stakeholder value map

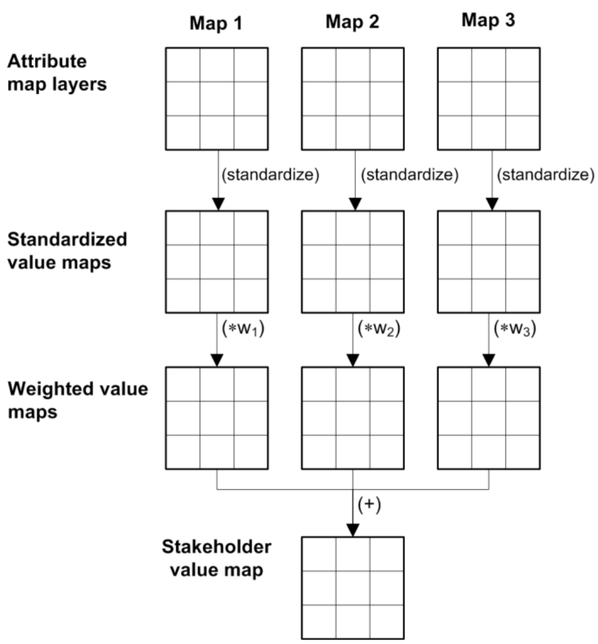


Figure 6.2. Generating a stakeholder value map.

6.2.1. Collection of attribute map layers

Collection of attribute map layers requires definition of the objectives of all stakeholder and the attributes linked to these objectives as well as collection of the spatial data describing these attributes. Since these data are collected from a wide range of sources, this step results in a set of attribute map layers with different spatial scales and accuracies. All attribute maps are converted to a raster format stored into the GIS and fitted into a common grid in order to allow cell-to-cell analysis.

6.2.2. Valuation

Valuation consists of transforming an attribute map layer into a standardized value map. A standardized value map is obtained by reclassifying the data portrayed in an attribute map layer using expert judgment. Value functions are used to represent human judgment mathematically. A value function translates an attribute value into a value score (Beinat, 1997). Equation (6.1) gives an example of an exponential single-attribute value function V for attribute x, where a, b and c are relevant coefficients.

$$V(x) = a + b\mathrm{e}^{cx} \tag{6.1}$$

A value function thus can be defined explicitly by specifying its shape (e.g., linear, convex or concave) or implicitly by assigning a value to each attribute class. Table 6.1 provides an example of a value function that is implicitly defined. The table links depth classes to suitability for a tidal energy device.

Table 6.1. Implicit definition of a value function.

Sea depth [m]	Value
< 10	1
10-20	7
20-50	10
50-100	4
100-500	0
500-1000	0
1000-5000	0

6.2.3. Generating stakeholder value maps

A stakeholder value map is generated by combining all standardized value maps relevant to a specific stakeholder (Figure 6.2). The MCA method used is based on multi-attribute value theory usually referred to as weighted summation (Janssen, 1992). Weighted summation involves four steps: 1) standardize the scores per attribute; 2) set the weights; 3) multiply the weights by the standardized scores; and 4) aggregate the scores. As the value maps are already standardized on a 0-10 range, the first step is to set the weights. Expert judgment is used to set the initial set of weights. Next, the stakeholder value maps are multiplied by these weights and aggregated. In a GIS, this is performed using weighted overlay operations and results in an aggregated value map for each stakeholder. For the value map of stakeholder j, the value of each cell V is calculated using the following equation:

$$V_j = \sum_{i=1}^{I} w_i \cdot s_{ij} \tag{6.2}$$

Where s_{ij} is the standardized value of a cell of the standardized value map for stakeholder j with respect to the ith attribute, and the weight w_i is a normalized weight, so that $\Sigma\ w_{\mathrm{i}} = 1$. The weights represent the relative individual importance of those attributes that are relevant to stakeholder j. Implicit in Equation (6.2) is the assumption that the value function of one attribute is independent of the value function of another attribute but also that a bad performance on one attribute can be compensated with a good performance on another attribute. In practice, these assumptions will only hold if the ranges of the scores of these attributes are not too large.

6.2.4. Using local knowledge to adjust and validate the stakeholder value maps

Local knowledge is used to validate and correct the value maps. Corrections are needed if data are not available or inaccurate, have different spatial scales, or if disagreement exists between stakeholders about data quality. Feedback is needed to assess and discuss the value functions and weights used. Expert judgment is used to set the initial weights and value functions. It is possible to ask participants to make changes in these weights and functions directly, yet in practice it is not easy for participants to understand the implications of these changes. However, the resulting stakeholder value maps are usually easy to understand for most stakeholders. It is therefore easier to ask the stakeholders to make their changes directly on the map.

The value map is presented to the stakeholders on the Touch table. Stakeholders can adjust the values directly on the map. This is supported by drawing and scoring tools. With the drawing tool, participants can express their opinions about a value map displayed on the Touch table. Participants can draw color-coded lines and add annotations about these lines on top of a value map of the area to indicate the high or low importance of a particular map location. The tool stores stakeholder input in a separate layer. With the scoring tool, participants can modify the value map displayed on the Touch table using the input provided previously with the drawing tool.

6.3. Negotiation support tools

The negotiation support tool uses the value maps generated in the previous workshop to support the stakeholders in finding the optimal location for the off-shore tidal energy devices. These tools supports the negotiated allocation of tidal energy devices and includes two types of tools, namely tools for mapping trade-offs between stakeholders and feedback tools on overall value.

6.3.1. Tools for mapping trade-offs between stakeholders

These tools use the stakeholder value maps to create a dynamic negotiation map showing potential trade-offs between stakeholder objectives (Arciniegas et al., 2011). The values stored in each stakeholder value map were calculated with MCA at a cell level using Equation (6.2). The dynamic negotiation map utilized these stakeholder values to highlight those cells within the study area that are potentially suitable or unsuitable for allocating tidal energy sites. By overlaying all stakeholder value maps, each cell of the study area was associated to all stakeholder values A_j from a set of J stakeholders. The tool allowed users to set thresholds in order to make a selection of cells from a set of cells ranked by their stakeholder values. Selected cells are referred to as a trade-off set T, which was represented by dynamic labels appearing on top of the cells.

Let C be the entire set of N cells of the study area. The set of cells C is defined as:

$$C = \{c_1, c_2, \ldots, c_n\} \text{ for } n = 1, \ldots N \tag{6.3}$$

A trade-off set T is defined as the overlap between high-value cells for one stakeholder with low-value cells for one or more different stakeholders, or vice versa. The users define the number of cells to be included in the selection of high-value cells for stakeholder x and low-value cells for stakeholder z. More specifically, subset T results from the intersection between two subsets of C: subset H_x containing those cells with the highest values for stakeholder J_x and subset L_z containing those cells with the lowest values for stakeholder J_z. Sets containing high and low values for each stakeholder are selected on the basis of two user-defined thresholds: number of high-value cells f_h and number of low-value cells f_l.

These two thresholds are used to define the selection of high and low value cells, respectively. The set $H_x(f_h)$, which contains the H high-value cells ranked by their stakeholder value V_x on the basis of threshold f_h, is defined as:

$$H_x(f_h) = \{h_1, h_2, \ldots, h_h \mid h \in C, V_1 \geq V_2 \geq \ldots \geq V_h \wedge H_x \geq f_h\} \quad (6.4)$$

Set L_z, which contains the L low-value cells ranked in ascending order by their stakeholder value V_z on the basis of threshold f_l, is defined as:

$$L_z(f_l) = \{l_1, l_2, \ldots, l_l \mid l \in C, V_1 \leq V_2 \leq \ldots \leq V_l \wedge L_z \geq f_l\} \quad (6.5)$$

The overlap between high-value cells for stakeholder x, and low-value cells for stakeholder z is defined as $H_x \cap L_z$. The overlap between high-value cells for stakeholder z, and low-value cells for stakeholder x is the opposite: $H_z \cap L_x$. Hence, the trade-off set for stakeholders x and z is the union of both sets:

$$T_{xz} = (H_x \cap L_z) \cup (H_z \cap L_x) \quad (6.6)$$

A similar procedure is followed for all J stakeholders. The total set of cells T with trade-offs between all J stakeholders is defined as:

$$T = \bigcup_{\propto=1}^{J} \bigcup_{\beta=\propto+1}^{J} T_{\alpha\beta} \quad (6.7)$$

Where α and β constitute all possible combinations of elements from the set of stakeholders J.

In the negotiation map, the set of selected cells showing trade-offs was highlighted using labels. A label consisted of a fixed sequence of color-coded capital letters appearing on top of each selected cell as follows: high-value cells were labeled with blue characters and low-value cells with red. For example, participants could use the tool to highlight the first 100 cells with the highest scores for stakeholder ‘Commercial shipping’ and those 100 cells with the lowest scores for stakeholders ‘Fisheries’ in order to display trade-offs between these two stakeholders. In this case, a sequence of two capital letters ‘C F’, colored respectively blue and red, was displayed representing the values associated with those two stakeholders. All other cells did not display any labels.

6.3.2. Feedback tools on overall stakeholder value

The evaluation tools calculated the overall value of each stakeholder value map, which showed the effect of allocations for each stakeholder. A device set D is a subset of C containing those Y cells that have been allocated a tidal energy site. The user directly specifies this set on a raster map. All cells in D are associated a value E_y equals to one. It is assumed that any cell in C can either have allocated a tidal energy site or not. Hence, the set of unallocated cells U corresponds to the remaining $N – Y$ cells and are assigned a value $E_{(n\text{-}y)}$ equals to zero. Thus, sets D and U are defined as:

$$D = \{d_1, d_2, \ldots, d_y \mid E(d_y) = 1\} \qquad D \subseteq C \quad (6.8)$$

$$U = \{u_1, u_2, \ldots, u_{n\text{-}y} \mid E(u_{n\text{-}y}) = 0\} \qquad U \subseteq C \wedge D \cap U = \varnothing \quad (6.9)$$

For stakeholders for whom allocated cells are relevant, the aggregated value A for stakeholder j is calculated as the average of the values V_j of all elements in subset D:

$$A_j = \sum_{y=1}^{Y} V_j / Y \tag{6.10}$$

For stakeholders for whom non-allocated cells are relevant, the aggregated value A for stakeholder j is calculated as the average of the values V_j of all elements in set C:

$$A_j = \sum_{n-y=1}^{N-Y} V_j / N \tag{6.11}$$

The output of this tool is an overall stakeholder value for each stakeholder involved. These values are plotted in a bar chart that portrays the various effects of the allocation of tidal sites.

6.4. Mapping stakeholder values for the Mull of Kintyre

Key stakeholders for the potential Kintyre tidal energy extraction site were identified and two stakeholder workshops held with the purpose of identifying suitable locations for the tidal energy extraction devices. The first workshop, called the 'local knowledge workshop', focused on mapping the use values of the stakeholders involved. The second workshop, called the 'negotiation workshop' focused on the identification of the optimal locations for the tidal energy devices. Figure 6.3 shows participants of the local knowledge workshop sitting around the Touch table.

Figure 6.3. Participants of the local knowledge workshop around the Touch table.

The value mapping tool introduced in Section 6.2 was implemented during the ‘local knowledge’ workshop. Stakeholders participating in the local knowledge workshop were representatives of the local fishermen, the Campbeltown Sub-Aqua Club, the Campbeltown Sailing Club and a local wildlife tour operator. The purpose of the workshop was to collect spatially explicit data on the interests of local sea-users at relevant spatial scales. This was achieved using the drawing and scoring tools on the Touch table in three steps, which are shown in Figure 6.4 for stakeholder group ‘Fisheries’. A full report of the workshops can be found in Janssen (2011).

The stakeholder value maps were created in three steps (Figure 6.4). In the first step, participants were shown the GIS attribute map layers used to produce the stakeholder value maps (Figure 6.4a). In preparation for the workshop, six stakeholder value maps were generated: 1) tidal energy; 2) commercial shipping; 3) commercial fishing; 4) recreational shipping; 5) tourism; and 6) environment. Weights were used to obtain a value score for each stakeholder and were set and specified using expert judgment. Stakeholder-specific values from 0-10 were assigned to a grid of 500 m x 500 m cells, based on the size of the study area and the likely size of tidal energy devices to be installed. For example, the value for stakeholder ‘tidal energy’ was calculated as the weighted sum of four criteria linked to four attribute maps: tidal flow, depth in meters, type of seabed, and distance to port. In the second step, each participant was asked to use the ‘drawing tool’ to draw locations of particular significance to their stakeholder group on the Touch table map (Figure 6.4b). These drawings constituted the basis for the modification of an original stakeholder value map and were automatically incorporated into the GIS so they could be overlaid with any attribute or value map. In the third step, each participant was asked to re-value the map based on these drawings by changing the cell values of the original map using the ‘scoring tool’. The result was a new stakeholder value map that included views based on stakeholder knowledge (Figure 6.4c).

The main result of the workshop consisted of three new stakeholder value maps based on the knowledge of the local fisheries, recreational shipping and tourism stakeholders (Figure 6.5). Stakeholders had no difficulty using the tool to change the values on the map. The fishermen gave high values to the areas marked in the previous round as important fishing grounds and important transit routes. They gave low values to the areas were the tide was considered too strong for fishing (Figure 6.5a). Input from representatives of the local sailing club stated that the whole area was important as yachts need sufficient space for tacking (Figure 6.5b). As no regular tourist excursion boats go around the Mull, most of the area was considered to have a low value. The horizontal green line represents the route of a seasonal tourist ferry (Figure 6.5c).

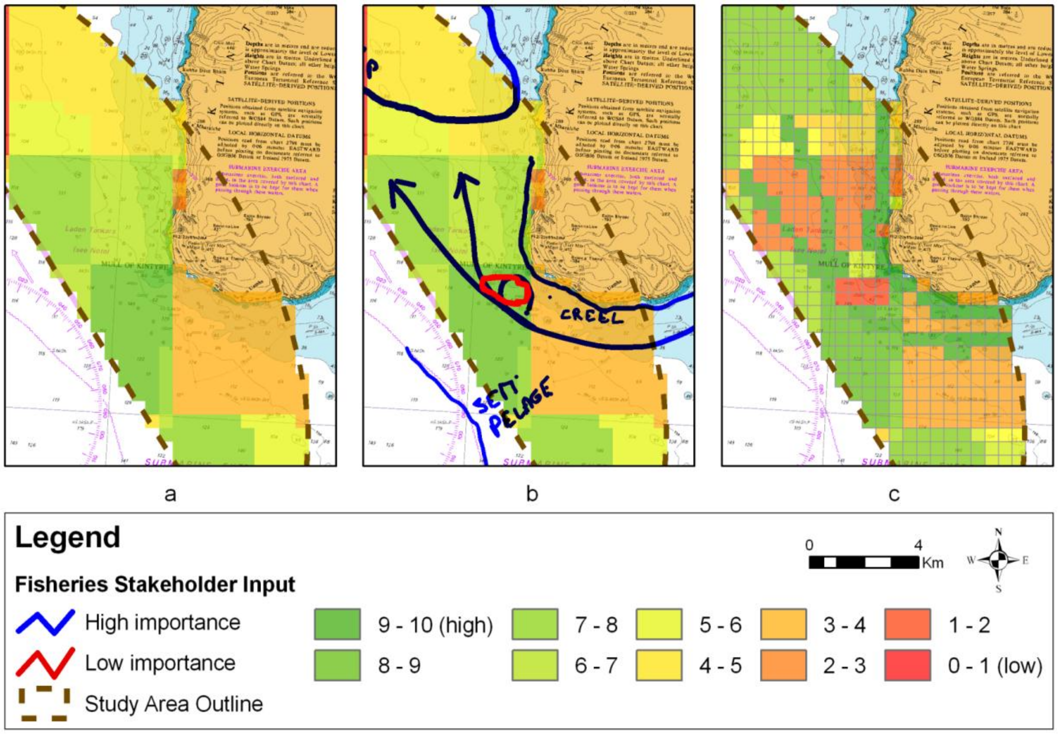


Figure 6.4. Three steps to create a stakeholder value map for fisheries: the base value map (a), areas of importance (b) and the re-valued map (c).

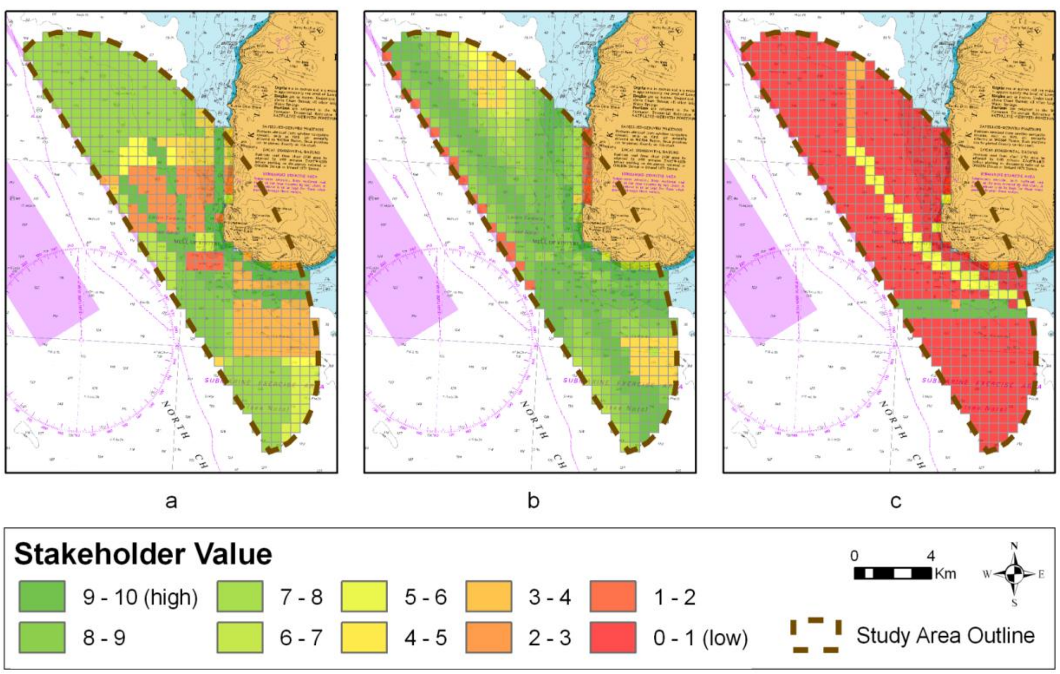


Figure 6.5. Revised stakeholder value maps for fisheries (a), recreational sailing (b) and tourism (c).

6.5. Supporting negotiated solutions for allocating tidal energy sites for the Mull of Kintyre

Representatives of the Campbeltown Sailing Club, wildlife tour operators, local fishermen, Clyde Fisherman's Association, Scottish Renewables, and Argyll & Bute Council participated in the negotiation workshop. The stakeholder value maps created by stakeholders during the first workshop were used as the input to the negotiation support tools. The purpose of the workshop was to reach a consensus on the best locations for situating potential tidal energy devices. Using the negotiation support tools, the participants identified negotiable cells optimal for one stakeholder but not for the other and vice versa. Participants were asked to trade negotiable cell alternatives as follows: two cells (0.25 km^2: ~40 MW), five cells (1.25 km^2: ~100 MW) and ten cells (2,5 km^2: ~200 MW). Participants were further asked to evaluate the data sources upon which the negotiations were based and to complete a survey questionnaire related to their background, the support tools and the tasks they had to perform.

The procedure to trade negotiable cells using the negotiation support tools is illustrated in Figure 6.6. First, participants zoom into a location of interest within the study area (Figure 6.6a). Using the trade-off tool, trade-offs between three stakeholders groups (Tidal energy (T), Commercial (C) and Social (S)) are highlighted on the map based on threshold set by the participants (Figure 6.6b). Based on this information, participants negotiate an allocation of tidal energy sites for a number of cells (Figure 6.6c).

To make the information presented manageable for the participants, the six stakeholders were combined into three groups: 1) Tidal; 2) Commercial (commercial shipping and commercial fishing); and 3) Social (recreational shipping; tourism and environment). Figure 6.6b shows a negotiation map, which highlights the best (blue) and worst (red) cells for stakeholders: Tidal Energy (T), Commercial shipping (C) and Social (S). In order to highlight trade-off information on the map, the negotiation tool has a number of interactive sliders for each stakeholder, with which users can specify high or low thresholds for number of cells to be analyzed. By touching a slider and dragging it to a new position, users specified a number of cells (or the equivalent percentage of the study area) to be analyzed and ranked by their stakeholder values. Selected cells were highlighted with the color-coded labels. For example, if the participants chose to highlight the first 100 cells (2.5 km^2) with the highest scores for stakeholder group 'Tidal' and the first 100 cells with the lowest scores for stakeholder groups 'Commercial' and 'Social', a sequence of three capital letters 'T C S', colored respectively blue, red and red, would appear on top of the selected cells. This information was used to guide users as they allocated tidal energy devices to target cells across the study area (Figure 6.6c). When new allocations were made, the evaluation tool would recalculate the overall stakeholder values.

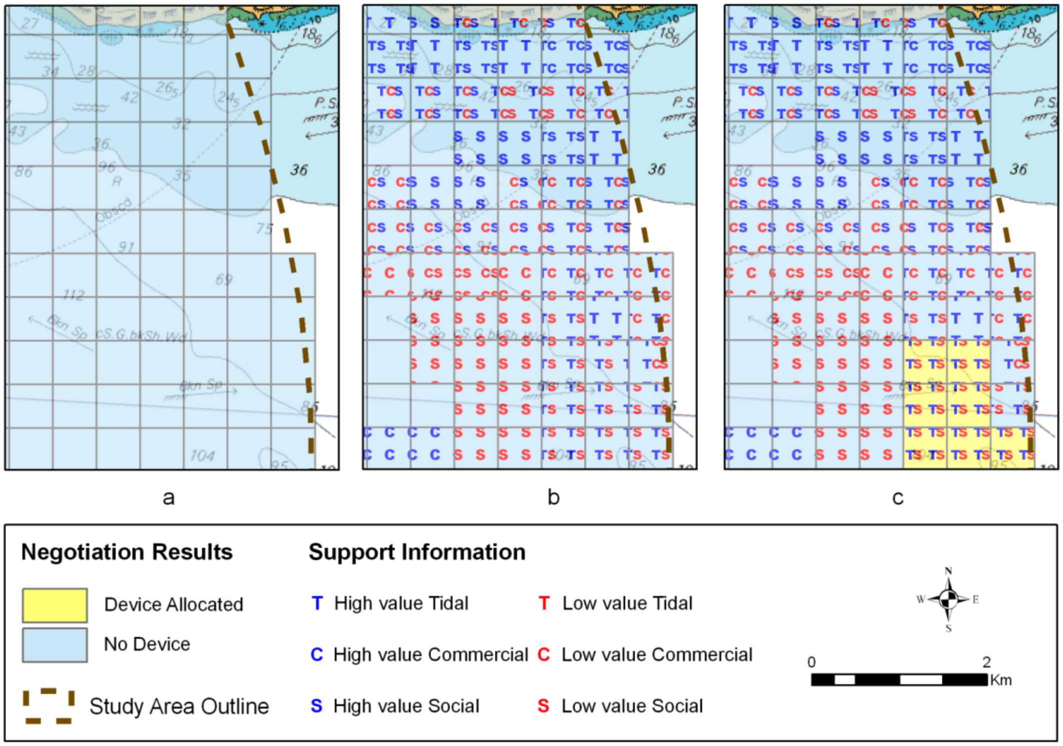


Figure 6.6. The nautical chart (a), the best and worst areas for three stakeholders (b), and the negotiated result (c).

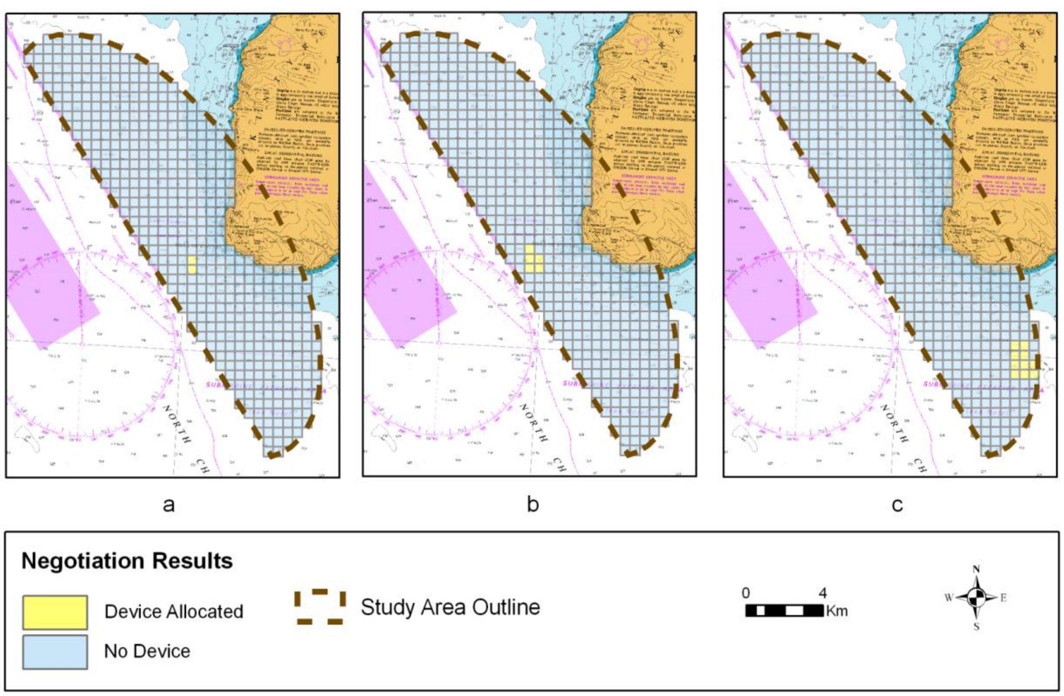


Figure 6.7. Tidal energy device allocation for the ~40 MW (a), ~100 MW (b), and ~200 MW alternative (c).

In the negotiation workshop, participants were asked to use the data supplied on the Touch table as a tool to help allocate devices within the study area. Initially, the scenarios were set at 10, 50 and 100 cell allocations. However, through discussion with the 'tidal energy' stakeholder, it was decided that arrays of this size were unrealistically large, given that ~20 devices could fit in one grid cell, and each cell may produce 20 MW of power on a spring tide. Therefore, the scenarios were amended and the participants were asked to allocate 2, 5 and 10 cells (~40, ~100 and ~200 MW, respectively) for tidal energy development. For the ~40 MW alternative participants selected two cells that were far offshore to avoid conflicts with other stakeholders with good tidal flows and not too deep (Figure 6.7a). Questions were raised about the quality of the tidal flow map.

Allocating 5 cells for the ~100 MW alternative appeared to be more difficult. A fisheries representative, who had not been present in the local knowledge workshop, questioned the fisheries value map. He indicated that the whole area was important to fisheries. The cells were shifted to the west to allow sufficient space for tacking between the Mull peninsula and the tidal energy devices (Figure 6.7b). For the ~200 MW alternative it was suggested by the recreational shipping representative that ten cells would interfere with yachting around the Mull if the cells were kept in the same area as previous alternatives, suggesting that further south would be more appropriate. Both fishing representatives agreed, stating that the southern part of the area had a low value for static fishing gear and semi-pelagic fishing (Figure 6.7c).

The effects of each of the three negotiated allocation alternatives were available as a bar chart displayed on a separate screen next to the Touch table. Each chart showed the overall stakeholder value for all six stakeholders of the Mull of Kintyre site. The overall values were calculated using Equations (6.10) or (6.11), depending on the stakeholder. Figure 6.8 shows the overall stakeholder values for each device allocation alternative. The current situation (no devices) was considered optimal for all current stakeholders with a value of 10 and no value for 'Tidal energy'. Locating tidal devices increased the value of tidal energy at the expense of all other stakeholders. The ~40 MW alternative increased the value of 'Tidal energy' to 5.73 at the expense of mainly 'Tourism' (Figure 6.8a). The ~100 MW alternative had a considerable effect on stakeholders 'Commercial shipping' and 'Fishing' (Figure 6.8b). The scores for the ~200 MW alternative showed that this alternative affects stakeholder 'Commercial shipping' the most (Figure 6.8c).

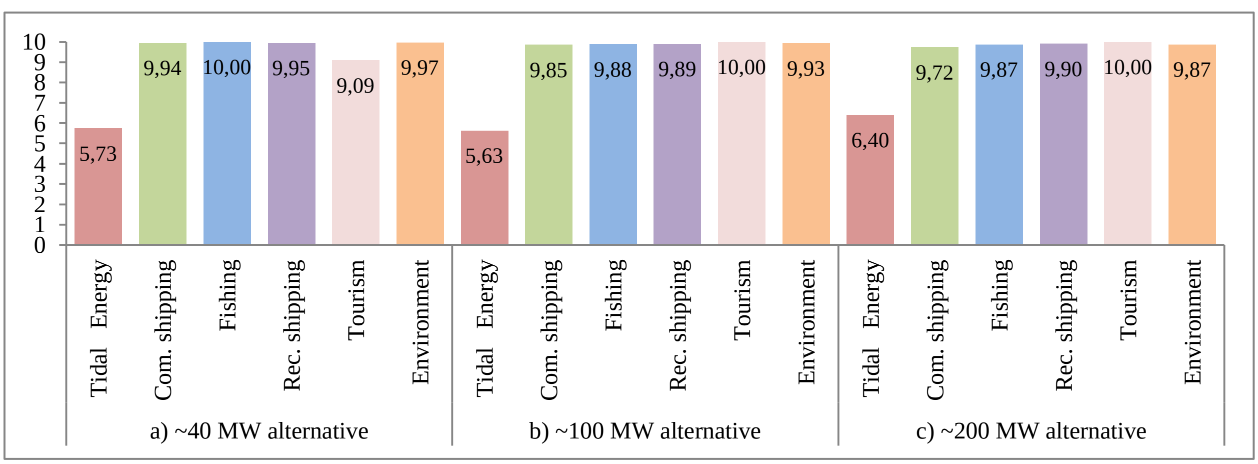


Figure 6.8. Overall stakeholder values for the ~40 MW (a), ~100 MW (b) and ~200 MW alternative (c).

6.6. Conclusions

In this study spatial decision support tools that were developed to support a terrestrial land use planning process in the Netherlands (see Arciniegas et al. 2011, 2012) were adapted to a marine spatial planning problem. The most important result from this project was the successful transfer of an approach developed for land use planning to a marine spatial planning problem. The detailed knowledge held by workshop attendees about the study area, land in the terrestrial case and sea in the current, was very similar. Two questions were asked at the beginning of this article:

- Can simple drawing tools and spatial evaluation tools be used to integrate expert knowledge and concerns of local stakeholders for the evaluation of potential sites of tidal energy devices?
- Can spatial evaluation tools be used to support the identification of the best compromise solution for the location of tidal devices?

Both questions are linked to the use of the valuation and negotiation tools. In this concluding section, the use of the valuation tool is discussed first, then the use of the negotiation tool and finally the use of both tools in a collaborative setting with the Touch table providing an interface between tools and participants. Conclusions are based on the workshop results, observations made during the workshop and the results of a questionnaire completed by the participants immediately after the workshop.

6.6.1. Value mapping tool

During the local knowledge workshop, all contributors became involved in working with all maps, even if they were not the key stakeholder, making the process even more interactive than originally planned. Participants combined their knowledge of the region, questioned each other's positions and further developed points made by others. People who live on the coast often take part in many activities, and work in many jobs (particularly in rural areas): the recreational sailor previously a fisherman; the Sea Search diver also a yachtsman. It would appear that multi-interest stakeholders can be beneficial for interactivity and knowledge-sharing and have an invaluable role to play in planning for future uses of marine space.

Using the value mapping tools, it proved possible to generate value maps that did not exist otherwise. This is reflected in the survey, where participants stated that 80% of the participants found the combination of knowledge from research with local knowledge helpful in dealing with the problem. Approaching the problem in two steps proved successful. With the drawing tool, the users identified relevant areas. In the next step, they zoomed in on these areas to alter the values at a more detailed level. Although there were lots of questions regarding the quality and accuracy of the attribute map layers, participants did not challenge the weights or question the aggregation methodology used to create stakeholder value maps. Instead, participants proved able and willing to directly change the value map using the value mapping tool.

In addition to improving the value maps, the workshop proved useful in creating consensus around the value maps. Participants that were present at both workshops took ownership of the local knowledge value maps in the negotiation workshop. During the preparation stage of the workshops, it was decided that the value maps for tidal energy, commercial shipping and environment were of sufficient quality and hence, would not be included in the local knowledge workshop. With hindsight, this was a mistake because it reduced ownership of this part of the information. For the same reason, it is recommended that the same participants attend both workshops.

6.6.2. Negotiation tool

The tools for mapping trade-offs proved advantageous for supporting the participants when allocating devices. To be able to present stakeholder values in a single map, it was necessary to combine six stakeholders into three groups. This loss of stakeholder-specific detail was overcome by consulting stakeholder value maps and underlying attribute maps during the negotiation. It was interesting to note that the participants went for acceptable locations rather than optimal. The trade-off tool supported this through setting thresholds. However, the tool which provided feedback on the overall value of the plan, and therefore could be used to find an optimal rather than an acceptable solution, was little used during the workshop. The evidence gathered during the workshops indicated a relatively harmonious status quo between different sectors using the sea space around the Mull of Kintyre. The stakeholder value maps indicated that similar routes are used by fishing, recreational sailing and tourism vessels but that no stakeholder prevents any other from using these routes. However, offshore development of tidal energy may place spatial restrictions on many of the current activities. This will fundamentally change the social dynamics of the use of the area. This could result in problems regarding safety because of narrowing transit areas, and loss of access for commercial use. Despite these limitations, the results from the negotiation workshop were promising, and stakeholders with opposing perspectives successfully managed to identify areas in which tidal devices might be situated with minimal disruption to existing activities.

6.6.3. Use of the Touch table in a workshop setting

The combination of the Touch table with spatial MCA effectively engaged all stakeholders at both workshops. Participants had little or no experience with this type of support, yet engaged easily with the process. Participants were satisfied with the results of the workshop and indicated that they would attend a follow-up workshop and recommended participation to others. The set-up of the system whereby participants sat face to face and manipulated the maps cooperatively helped to break down barriers and encouraged cooperation. Apart from the institutional context, there was little difference between the previous land use planning workshops and the current marine spatial planning workshop.

6.6.4. In conclusion

A good workshop is dependent on attendance of the right people. However, it is not always easy to persuade the right people to commit their time. A good workshop also depends on a cooperative attitude of the participants and a willingness to communicate their position. Furthermore, to create ownership of the stakeholder value maps, all stakeholders should attend both workshops. In summary, it can be concluded that:

- An approach developed for land use planning successfully resolved a marine spatial planning problem.
- Interactive value mapping addressed deficiencies in data and created credibility for value maps.
- Stakeholders with little experience in spatial decision support actively engaged with the spatial planning process.

Chapter 7

Synthesis and conclusions

7.1. Revisiting research objectives

This thesis has discussed a research methodology developed to incorporate a set of map-based tools into land use planning processes with conflicting objectives. The methodology, which involved a set of map-based tools, the Touch table and a series of collaborative workshops, was successfully applied to two planning processes, namely the land use planning process of the Bodegraven peat-meadow polder in the Netherlands and the marine planning process of the tidal energy site around the Mull of Kintyre in Scotland. The tools were implemented in workshops held with stakeholders of each decision process. Moreover, the effectiveness of the tools was assessed through controlled experiments with students at M.Sc. level. This thesis has addressed the following objectives:

1. To develop, implement and test a set of spatial tools that support the integration of stakeholder knowledge for designing and evaluating land use plans (Chapter 2)

2. To develop, implement and test a negotiation tool that supports collaborative allocation of land use amidst conflicting objectives (Chapter 3)

3. To analyze the effectiveness of map-based collaborative tools for land use planning (Chapter 4)

4. To apply the tools to planning processes in a collaborative workshop setting. This includes two applications in practice within two case studies for: land use planning (Chapter 5) and marine spatial planning (Chapter 6).

This chapter shows how these objectives have been addressed and synthesizes the major conclusions of this thesis (Sections 7.2-7.5). After discussing a number of implications for collaborative spatial planning, a list of recommendation for further research is provided (Section 7.6).

7.2. Integrating stakeholder knowledge for plan evaluation

This section addresses the first thesis objective. The evaluation of land use plans consisted of integrating different types of expertise using spatial MCA. A land use plan could be evaluated both numerically (as a set of aggregated criteria values) and spatially (as a set of criteria value maps) (Chapter 2). During an analysis workshop, a group of experts worked on the Touch table and used evaluation support tools to generate value maps and rank alternative plans on a list of criteria. These results were used as feedback by the participants to detect inconsistencies on the value maps, make corrections and reevaluate the land use plans. Participants could quickly detect these inconsistencies despite not really fully understanding the underlying mechanisms used to create the maps. This was possible because the tools are interactive, allowing participants to play with the information available and to generate output in real time. Another reason for this relates to the Touch table collaborative setup, which proved successful to stimulate dialogue between experts viewing a map, making them aware of the links between the different types of information used for evaluation. Reaching consensus on standardization and weights proved to be challenging issues during the workshops, mainly because these workshops were held with experts and not with decision-makers. The focus of the evaluation support lies mostly on integrating expert judgment, rather than on weighting. As long as the weights are clear from the beginning, it can be concluded that a combination of expert judgment, spatial MCA and the Touch table can support both the numerical and spatial evaluation of land use alternatives on the basis on a set of evaluation criteria.

7.3. Supporting negotiated land use allocation

This section deals with the second objective of this thesis. The design and implementation of tools to support negotiations for collaborative optimization of land use plans among conflicting objectives was discussed in Chapter 3. This negotiation support consisted of tools for mapping trade-offs between the interests of stakeholders, tools for allocating land use on the Touch table and tools for evaluating the allocation effects. Chapter 2 presented a method to evaluate land use plans collaboratively on the basis of ecological criteria. The support tools described in Chapter 3 made use of this method to evaluate plans on all possible criteria and to transform this information into spatially explicit trade-offs between stakeholder objectives. These trade-offs were mapped on the level of individual parcels to facilitate the identification of areas with potential land use conflict and to support participants in deciding which areas can be selected for a negotiated land use exchange. Exchanges were realized by painting new land uses on selected parcels on the Touch table. The effects of these exchanges were calculated dynamically as indicators and made available to participants.

The allocation support tools were used by stakeholders of the Bodegraven polder during a negotiation workshop. In this workshop, participants conducted an assignment aiming at improving the existing land use situation of the polder using the support tools on the Touch table. The participants managed to generate land use plans with higher qualities than the starting situation, even though these resulting plans looked different spatially. This was possible because the tool allowed participants to quickly find optimal spots suitable for negotiation, use their knowledge about the region to decide on land use changes, and see the effects of their decisions in real time. The formulation of the allocation assignment was a critical aspect of the workshop. For the tools to be used effectively, it was important that the assignment goals allow wins for all participants, i.e., that all quality scores can be improved upon, which would automatically guarantee an improvement on the overall plan quality. Establishing realistic assignment goals appears to be difficult for this type of workshops, particularly if the stakeholder scopes vary greatly. In fact, it cannot be affirmed with certainty whether this approach would work to support a negotiation workshop with local stakeholders, who are only interested in their own land, and stakeholder with much broader interests, such as municipal or even provincial authorities. Willingness to engage in land use exchanges and cooperative attitudes by negotiators are requisites for the successful use of the tools. It can be concluded that providing stakeholders with information about trade-offs between objectives directly on a map can support stakeholder negotiations on the optimization of existing plans as long as the stakeholder scopes are similar in extent and there is willingness to negotiate and a cooperative attitude by stakeholders.

7.4. Effectiveness of map-based tools

This section is linked with the third thesis objective. The effectiveness of the land use allocation and evaluation tools was analyzed using a framework developed for this research that included empirical tests of tool usefulness, tool clarity and decision-making impact. Tests were run with 30 M.Sc. students, who were asked to play stakeholder roles and use the tools both individually and collectively in a controlled workshop setting. Effectiveness was measured on the basis of user perceptions, measured performances and spatial results (Chapter 4). The three tools utilized parcel-based quality information derived with spatial MCA (as presented in Chapter 3) to facilitate clarification and negotiation of spatial trade-offs between stakeholder objectives. The difference was in how each tool presented this trade-off information. The first tool consisted of objective-specific value maps in printed form; the second presented this information quantitatively on individual parcels on top of a digital land use map; and the third tool provided this information qualitatively on individual parcels on top of the digital land use map.

Results showed that perceived effectiveness of map-based decision support tools had a close relationship with observed effectiveness. The tool that provided the most detailed information was not considered to be the most effective. This was supported by its measured performance as it led to plans with the worst quality. The qualitative tool proved to be the most effective both in the minds of the users as well as on the basis of performance measures. Plans with the highest qualities were obtained using this tool. The printed-maps tool accounted for the most and longest discussions as well as the most spatially different land use plans. It can be concluded that tools that provide users with information with a low level of complexity can trigger extensive discussion and extensive allocation work, both of which lead to land use plans of higher quality. On the other hand, tools that provide users with information with a high level of complexity triggered low decision-making performances of users, which can be associated with issues of cognitive effort, leading in turn to plans of lower quality. An important lesson from the experiments is that testing tools on students constitutes valuable means for empirically assessing tool effectiveness because using students as test subjects excludes the effects of local knowledge and direct stakes.

7.5. Using map-based tools in practice for collaborative planning

7.5.1. Land vs. sea

This section addresses the fourth objective of this thesis. The research approach discussed in this thesis was applied to two spatial planning processes with conflicting objectives. The first case study involved the reallocation of land use functions for a peat-meadow polder in Bodegraven, the Netherlands (Chapter 5). The second case study involved the identification of potentially suitable locations for off-shore tidal energy devices off the Mull of Kintyre, Scotland (Chapter 6). The main characteristics of both case studies are summarized in Table 7.1.

The research approach (tools, Touch table, workshops), originally developed to support a collaborative land use planning process, was successfully applied to support a marine planning process. Although both case studies were fundamentally different in nature and application domain (land vs. sea) and the ownership of decision space (land is privately owned while British seabed is owned by the Crown state), it was possible to use the lessons learned on the terrestrial domain and the similarities between both cases to modify the approach and translate it to the marine domain. The most important similarities shared by both case studies included the expected modification of the functions of the study area, the resultant arising of spatially explicitly conflict between the interests of stakeholders who make use of the area, and the availability of spatial data relevant to each stakeholder. In order to implement the original land-based approach within see planning, some modifications had to be made. For the Bodegraven polder, a vector-based data model was used because polygons represent land parcels realistically enough. A raster grid with a cell size of 500 m x 500 m was used for the Mull of Kintyre tidal site because size and shape are not as important when representing allocated tidal devices

Table 7.1. Characteristics of the two case studies discussed in this dissertation.

Aspect	Case 1: Bodegraven (NL)	Case 2: Mull of Kintyre (UK)
Domain	Land	Sea
Area study site	4672 ha	12975 ha
Spatial units	Land parcels	Uniform cells
Data model	Vector (polygons)	Raster (cells)
Decision space	Land use	Sea use
Stakeholders	Experts and institutional	Experts and locals
Ownership of space	Private (land)	None (Crown state owns seabed)
Driving factor of process	Soil subsidence	Adoption of renewable energy
Length decision process	10 years	Not specified
Criteria/attribute map layers	12	15
Final product	Land use plans	Maps for tidal site locations
Evaluation product	Four maps for stakeholder objectives	Six maps for stakeholder value
Number of workshops	3 (analysis, design, negotiation)	2 (local knowledge, negotiation)

Table 7.2 shows the major features of the support provided for both case studies. The approach was originally implemented during three consecutive stakeholder workshops for Bodegraven (analysis, design and negotiation), held with governmental and non-governmental stakeholders. Each of the three tools was linked to the Touch table and implemented in one workshop as follows: drawing tools to support communication in a design workshop, spatial evaluation tools in an analysis workshop and allocation tools in a negotiation workshop. For the Mull of Kintyre, two workshops (local knowledge and negotiation) were held with stakeholders, such as local users of the region and experts. Design and analysis workshops were combined into one ‘local knowledge workshop’. Drawing and valuation tools were implemented in the local knowledge workshop to support communication for mapping stakeholder values.

In a similar way as with the land use application, the results of the local knowledge workshop were used afterwards during a ‘negotiation workshop’, where negotiation tools were implemented to support spatial allocation for the identification of locations suitable for tidal energy sites. The local knowledge workshop successfully helped stakeholders to identify, highlight and structure their preferences and concerns about the study site, whereas for Bodegraven, the design workshop helped structure stakeholder views of future land use scenarios for the polder. The local knowledge workshop also facilitated the identification and bridging of gaps in existing spatial information. This was possible because the stakeholders were able to change the values directly on the map. As for the analysis workshop for Bodegraven, the analysis support helped participants to find inconsistencies in the spatial information available. Value maps could be redrawn to see the effects of adjusting both weights and valuation rules but could not be modified directly. This proved to be an important difference between both case studies. The negotiation workshop proved effective to help stakeholders build consensus on the most suitable areas for potential development of tidal energy sites.

Table 7.2. Comparison of provided support for the two case studies discussed in this dissertation.

Type of support	Case 1: Bodegraven (NL)	Case 2: Mull of Kintyre (UK)
Communication		
Design support	Drawing feedback on plans	Drawing locations of importance
Interaction with map	On land use plans	On value maps
Main product	Drawings of stakeholder feedback	Drawings of stakeholder values
Main obstacle	Getting participants	Data quality and completeness
Spatial evaluation		
Analysis support	Criterion value maps	Stakeholder value maps
Interaction with map	Limited: value table	Direct on value maps
Main product	Criteria and objective value maps	Revised stakeholder value maps
Main obstacle	Assessment of local knowledge	Data quality and completeness
Spatial allocation		
Negotiation support	Per land use type	Per stakeholder group
Interaction with map	On land use map	On map of allocated devices
Use of aggregated values	Moderate	Marginal
Main product	Land use map, aggregated values	Allocated devices, aggregated values
Main obstacle	Formulation of assignment	Information too aggregated

The major conclusion from these two applications is that the workshop concept proved to be a valuable tool for communication and integration of stakeholder knowledge as well as for reaching consensus at different stages of a planning process. Collaborative workshops that are designed according to the frames for map use constituted meaningful platforms in which stakeholders could work together and address issues related to the use or functions of an area at any stage of the process. It is essential that the complexity of the tools gets increased as the planning process progresses, the participants are carefully selected and that workshops tasks are clearly defined. For workshops that are held at early stages of the planning process, simple drawing tools are effective because the focus is on communication and exchange of knowledge between stakeholders for framing the decision problem on the basis of different stakeholder views. Having stakeholders use simple drawing tools on a GIS environment to draw their ideas and exchange opinions on the planning issues on the Touch table successfully supported these tasks. For land use planning, the drawing tools were used by stakeholders to indicate strong or weak aspects of several land use alternatives as well as to indicate where plans can be modified. For marine spatial planning, the drawing tools allowed stakeholders to mark on the map areas of high or low importance, depending on their specific interests.

An analysis workshop proved to be an effective means to integrate expert knowledge for assessing land use alternatives. For the case of land use planning for the Bodegraven polder, a crucial aspect of the evaluation tools was the possibility for multiple users to interactively modify expert scores or change weights and then quickly see the effects of these changes as value maps and aggregated scores that could be ranked. For the case of marine spatial planning in the Mull of Kintyre, one of the most important aspects of the evaluation tools was the possibility to assign and change scores to spatial units directly on a stakeholder map and see in real time the aggregated values for each stakeholder. This type of interactivity was possible using the Touch table in the workshop.

Regarding the allocation tools implemented in a negotiation workshop, it is concluded that the MCA-based negotiation support provided directly on the map proved suitable and straightforward for use by multiple participants to support two cases of collective allocation of functions, namely the optimization of a land use plan by multiple participants in a workshop setting and the collective identification of potentially suitable locations of energy devices. In both case studies, the tools allowed for a quick identification of trade-offs on the map, which facilitated negotiations to support reallocation of land uses exchanges and locations of tidal energy devices. The effects of the allocation were quickly assessed and readily available. It can be concluded that map-based tools that are implemented within in an instrument such as the Touch table and are used in policy workshops need to be simple, interactive and must provide feedback quickly both on the map and quantitatively.

7.5.2. Main obstacles of both case studies

The assessment and integration of expert and local knowledge was successfully supported for both case studies. However, in the case of Bodegraven, participants of the analysis workshop, who were mostly experts, found it at times challenging to specify the value function using a 0-10 rating scale for some criteria. As for the Mull Kintyre, although incorporating and assessing local knowledge directly on the Touch table map worked well, participants questioned the quality and completeness of some of the underlying maps. Feedback from the local knowledge workshop will be used to define the need for additional data for a follow-up workshop.

This approach utilizes the outputs of previous workshops as input for an ensuing workshop. Thus, this approach requires that stakeholder representatives attending two consecutive workshops agree with previous outputs. This turned out to be a problem for the Mull of Kintyre as representatives of the fisheries participating in the second workshop did not agree with the value maps created during the first workshop. Although the on-the-map negotiation support provided was used intuitively by participants, it is important that participants understand that this information is aggregated and misses detail. It is essential to make the connections explicit between previous workshops, particularly their outputs and how these inputs are being used in the negotiation workshop. For the Mull of Kintyre, aggregating stakeholder into three groups, hence three stakeholder value maps, proved to be more challenging than the aggregation used for Bodegraven.

Finally, cooperation is a must. This means that workshop participants need to be willing to share their knowledge as well as to listen to other participants in order to learn about other standpoints regarding the future use for a given study whole area. This can be challenging to achieve, especially in cases when sharing such information may have financial implications for stakeholders. For example, fishermen were not really happy to reveal their fishing routes during the workshop if other fishermen were present. Some farmers’ representatives refused to participate in workshops as they are only interested in their own land, which constitutes their main source of income. It is thus important that participants understand that: 1) such cooperation will only facilitate the inclusion of their knowledge as information in the decision support tools so that it can be taken into account by decision-makers; and that 2) if stakeholders are reluctant or refuse to share their knowledge, this will ultimately be detrimental for their own interests and may actually make the outcomes of the decision process incomplete, less realistic and possibly more unfair.

7.5.3. Added value of using the Touch table

The effectiveness of the Touch table as a support instrument for collaborative policy workshops was successfully demonstrated in this study. The Touch table proved to be not only an attractive ‘gadget’ but actually facilitated tasks involving small group collaboration, particularly dialogue and discussion around maps between different types of stakeholders for the three types of workshops. In conclusion, presenting maps on the Touch table can be helpful means of communication, analysis tools and negotiation support platforms between stakeholders with different backgrounds. Particularly, based on the experiences from both case studies, the Touch table is probably most appropriate for planning situations involving the following characteristics of information and actors:

- A need to communicate spatial plans and associated map-based information of an area to stakeholders. Local stakeholders of the polder needed to know why land use was to be rearranged. Local sea users needed to know that there were plans concerning off-shore renewable energy.
- Availability of large amounts of spatial information at different levels of complexity. For Bodegraven, twelve criteria maps were combined to generate four stakeholder objective maps. For the Mull of Kintyre, fifteen attribute map layers were used to generate six stakeholder value maps.
- Different sources of expertise to be integrated. Bodegraven required the involvement of experts from ten different disciplines. The Mull of Kintyre involved six disciplines.
- Conflict between the interests of stakeholders with different scopes. Farmers are interested in their own land, fishermen in their fishing areas. Institutional stakeholders are typically concerned with the totality of an area. The Touch table helps bring balance between big and small pictures.

7.5.4. Implications for spatial planning

This thesis has demonstrated how map-based tools can be linked to the Touch table and successfully incorporated through policy workshops in two different planning processes. Common features of both planning processes included potential conflicts between interests of stakeholders and decision variables with a clear spatial dimension, so that decision alternatives could be presented as maps. Both processes were still ongoing and featured a regional scale and stakeholders with local knowledge about the region and with diverse disciplinary backgrounds. Participants of all workshops showed willingness not only to participate in the workshops but also to share their views, engage in negotiations and adopt a give-and-take attitude. The approach is potentially applicable to a wide range of spatial planning processes provided these processes share to some extent the characteristics mentioned above. In summary, the application of the approach discussed in this thesis would be most promising for spatial planning processes with the following characteristics:

- Relevant information to be integrated comes from models such as MCA, GIS or mathematical models, which is common in environmental management or ecosystem-based approaches.

- A map scale at which stakeholders can have a feeling for the map. Both case studies featured a rural/regional scale but this approach can also be applied at a less coarse scale, for example in urban planning processes or community planning.
- Stakeholder objectives can be linked to attribute maps and then translated into stakeholder value maps. For example, objective 'maximize natural value' related to maps of ecosystems.
- The extent of conflict between the interests of stakeholders regarding a given area has an explicit spatial dimension. This makes it possible to use spatial MCA to clarify trade-offs and identify areas of potential conflict and opportunities for agreement in order to facilitate negotiations.
- Stakeholders of the planning process are willing to participate in workshops to discuss planning issues with each while working around maps. Likewise, stakeholders need to be willing to embrace new technologies, such as the Touch table.
- Stakeholders with different backgrounds: locals or experts with multiple discipline backgrounds. This can be applicable to spatial planning situations such as, environmental resource management, water management or other instances of marine planning, such as the allocation of off-shore wind farms or installation of off-shore devices for sustainable fishing.

7.6. Future research

This thesis has explored the use of map-based tools in stakeholder workshops to support collaborative planning processes. The research approach features an integration of GIS technologies and MCA models with the concept of a collaborative workshop and an interactive policy instrument in the form of the Touch table. The effectiveness of the approach was assessed and demonstrated within two different planning processes. Although both implementations were successful, a number of issues remain unexplored and can be addressed by future studies aiming to develop improved support tools that are used widely in practice.

The first two issues are linked to section 7.2 (integrating stakeholder knowledge). The first issue relates to how to transform local knowledge into formalized information that can be used for decision support. The current MCA-GIS model can be extended with more quantifiable definitions for objectives of subjective nature. For example, local opinions or interests, fishing grounds, cultural and historical quality or visual landscape qualities are difficult to make operational using the present valuation method. A combination of the present interactive scoring approaches, with value functions or membership functions can be an alternative to facilitate incorporating such information in MCA models.

A second issue deals with the inclusion of sensitivity analyses to complement the evaluation model. Stakeholder values, objective scores and total assessments of one spatial unit are sensitive to changes in weights. It is recommended to explore how to include sensitivity analysis and uncertainty measures at stages where evaluation weights have not been established yet and thus can still be discussed and adjusted. Sensitivity analyses would fit in the frame of an analysis workshop, for example, where stakeholders would be provided with real-time results sensitivity analysis. A new type of policy workshop exclusively devoted to reaching a consensus on weights for criteria and objectives can also be an interesting alternative. Visualization technologies can play an important role in communicating uncertainty results during such analysis workshops.

The third issue is connected to Section 7.3 (supporting negotiations for allocation) and involves including spatial characteristics of spatial units into the MCA evaluation model to make both the evaluation and subsequent negotiation more realistic and less dependent on subjective opinions. The aggregated MCA values for one individual spatial unit are not influenced by the value of neighboring units. Incorporating capabilities that support spatial relationships between spatial units that are relevant to the evaluation objectives into the evaluation tools could improve the credibility of the evaluation model and would automatically improve the negotiation and allocation tools. Users can get some sort of relief knowing that spatial relationships, such as connectivity (landscape or fishing lanes), clustering (ecosystems) and homogeneity (natural areas) are being included in the evaluations.

The fourth issue relates to Section 7.4 (effectiveness of tools) and involves how to complement empirical assessments of effectiveness with more robust tests. The same controlled experiments can be held both with real stakeholders and students with and without the tool in order to better assess the effectiveness of map-based tools and policy workshops. Comparing results obtained with students against those obtained with real stakeholders can provide insights about the added value of this type of tools for spatial planning and increase real-practice implementations. It is important to further explore carryover and learning effects for empirical evaluations of tool effectiveness, focusing on the relationships of such effects with cognitive effort and the level of both complexity and detail of the information provided by the tools. This thesis has shown that employing tools which stimulate discussions has a positive effect on the decisions made. It is recommended to further explore how properties of support tools such as level of detail, complexity of information or scale can trigger discussion and exploratory attitudes among participants of collaborative policy workshops.

The final fifth issue is linked to Section 7.5 (using map-based tools in practice) and deals with how to improve the design of the workshops. Further research should explore the effects of formulating adequate workshop assignments on the success of this type of approaches. Particularly, investigating the links between workshops assignments and the goals of each individual decision stage can improve the implementation of the tools and positively influence the willingness of stakeholder to engage in working with other stakeholders around the Touch table. Furthermore, exploring the relationships between the different groups of stakeholders and each type of workshop to facilitate selection of and definition of suitable workshop participants can lead to more balanced implementations. Finally, it is recommended to explore to what extent culture and decision-making types influence the successful application of the proposed workshop-based approach to planning processes in different parts of the world, particularly in areas with more power-based decision-making structures. This would involve investigating how to match country-specific decision structures with the workshop assignments, participants and goals.

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Nederlandse samenvatting

Ruimtelijke beslissingsondersteuning voor participatieve planning

Menselijke activiteiten, voornamelijk de wijziging van natuurlijke omgevingen tot bebouwde omgevingen, hebben een fundamentele rol gespeeld bij het vormgeven van onze planeet naar de huidige toestand. Ruimte is daarom uitgegroeid tot een belangrijke hulpbron voor de ontwikkeling van menselijke activiteiten over de hele wereld, vooral in dichtbevolkte gebieden waar ruimte steeds schaarser wordt. Het ontwikkelen van ruimtelijke plannen voor de toewijzing van menselijke activiteiten in een gebied vereist beslissingen en een zorgvuldige afweging van de korte termijn en lange termijn behoeften. Het bereiken van milieu-, sociale en economische duurzaamheid voor een steeds dichter bevolkte planeet met beperkte ruimte en natuurlijke hulpbronnen blijft een uitdaging voor vele disciplines, in het bijzonder ruimtelijke ordening. Ondanks recente vooruitgang in multidisciplinaire ondersteunende planningssystemen, is er nog steeds een behoefte aan methoden voor gezamenlijke ruimtelijke ordening tussen verschillende types van actoren.

Dit proefschrift gaat over de ontwikkeling, evaluatie en toepassing in de praktijk van beslissingsondersteunende instrumenten die samenwerking op basis van digitale kaarten faciliteren. Het proefschrift beschrijft een onderzoeksmethode om zulke instrumenten bij participatieve ruimtelijke planprocessen met conflicterende interesses van belanghebbenden te kunnen gebruiken. De methode bestaat uit drie samenhangende elementen: drie soorten digitale ruimtelijke instrumenten, een digitale interactieve kaarttafel genoemd de Touch table en drie soorten planningsworkshops. De drie instrumenten zijn bedoeld om drie planningstaken te ondersteunen respectievelijk: communicatie, ruimtelijke evaluatie en verandering van ruimtegebruik. De Touch table is een groot interactief computerscherm dat gebruikt wordt door het scherm aan te raken. Op de Touch table kunnen deelnemers gezamenlijk plannen ontwerpen, evalueren of aanpassen. Een planningsworkshop is een bijeenkomst waarin belanghebbenden bij elkaar zitten om de ruimtelijke functies van hun gebied te bespreken. De workshops worden opgebouwd in een reeks van drie: ontwerp, analyse en onderhandeling.

Hoofdstukken 2 en 3 richten zich op het technische ontwerp en het gebruik van de kaart gebaseerde instrumenten. In hoofdstuk 2 wordt het ontwerp van een analyseinstrument beschreven en gedemonstreerd. Dit instrument maakt gebruik van ruimtelijke multicriteria analyse, opgenomen in een geografische informatie systeem gekoppeld aan de Touch table. Dit is ontwikkeld om de integratie van kennis van verschillende bronnen van deskundigheid te ondersteunen met als doel het ruimtelijke evalueren van bestemmingsplannen. Een plan wordt ruimtelijke geëvalueerd op basis van waardekaarten voor verschillende criteria. Het instrument werd gebruikt tijdens een workshop met deskundigen die betrokken zijn bij het planvormingsproces van een Nederlandse veenpolder. De waardekaarten worden op de Touch table gepresenteerd, getoetst, gewijzigd, en besproken. Na weging en aggregatie van de criteria kunnen waardekaarten worden opgeteld tot een waardering voor beleidsdoelen voor landbouw, bodem en water, landschap, natuur en een totaal waarde van een plan. De waardekaarten blijken effectieve middelen te zijn om de discussie tussen deskundigen te ondersteunen.

Hoofdstuk 3 laat zien hoe een instrument voor de ruimtelijke allocatie van functies in elkaar zit. Het allocatieinstrument maakt gebruik de van de door middel van ruimtelijke multicriteria analyse gemaakte

waardekaarten en combineert deze informatie om potentieel geschikte locaties voor het uitruilen van grondgebruiksfuncties op de kaart te identificeren zodat de kwaliteit van een plan vergroot kan worden. Deelnemers worden direct op kaart geïnformeerd over zulke mogelijke locaties en maken gebruik van deze informatie om te onderhandelen en vervolgens consensus met elkaar te bereiken voor het uitruilen van functies van landspercelen. Het instrument wordt aan de Touch table gekoppeld en tijdens een onderhandelingsworkshop geïmplementeerd met belanghebbenden van de veenpolder. Met hulp van het instrument kunnen deelnemers effectief de relatieve kwaliteiten van de huidige grondgebruikssituatie van de polder verbeteren. Deelnemers hebben door het gebruik van het instrument een aantal consensus plannen gegenereerd die ruimtelijk sterk verschillen maar met minimale verschillen in kwaliteit. Ondanks dat sommige deelnemers de onderliggende multicriteria analyse niet helemaal doorzien, krijgen ze toch een gevoel voor de implicaties gedurende de onderhandeling.

In hoofdstuk 4 wordt de evaluatie van de beslissingsondersteunende instrumenten behandeld. Het hoofdstuk gaat vooral over het systematische evalueren en toetsen van de effectiviteit van de ontwikkelde instrumenten. Het hoofdstuk beschrijft een empirische analyse om de effectiviteit van de instrumenten te evalueren op basis van drie aspecten van de instrumenten: bruikbaarheid, duidelijkheid van geleverde informatie en beslissingsimpact. De instrumenten werden met een controlegroep van studenten systematisch getoetst. Deelnemers aan het experiment werden gevraagd om de rollen van belanghebbende te spelen en vervolgens de instrumenten te gebruiken om verschillende allocatieopdrachten zowel individueel als collectief te vervullen. Dertig studenten hebben in totaal 120 ruimtelijke plannen gemaakt. Gegevens over de prestatie van de deelnemers werden opgenomen door middel van vijf methoden: voor- en na-enquêtes, observatoropmerkingen, video-opnames en ruimtelijke analyses. Individuele en groepsresultaten van het experiment worden geanalyseerd op basis van de percepties van de deelnemers en op basis van de kwaliteit van het resultaat. Het experiment liet zien hoe de inspanning van de deelnemers samenhangt met de aard en hoeveelheid van de aangeboden informatie.

De hoofdstukken 5 en 6 beschrijven twee praktijktoepassingen van de voorgestelde aanpak. Hoofdstuk 5 beschrijft hoe de reeks van drie workshops toegepast kan worden in het planningsproces van een Nederlandse polder. Drie workshops (ontwerp, analyse en onderhandeling) werden achtereenvolgend gehouden met belanghebbenden van de polder. Het hoofdstuk beschrijft hoe doelen, deelnemers, opdrachten en instrumenten specifiek zijn voor elke workshop en hoe de resultaten van een workshop gebruikt kunnen worden bij een volgende workshop. Uit de workshops blijkt dat zowel formaat als niveau van detail van de aangeboden ruimtelijke informatie belangrijke aspecten zijn die bij elke workshop aan moeten sluiten.

Hoofdstuk 6 demonstreert hoe de onderzoeksmethode, die oorspronkelijk voor ruimtelijke ordening bedoeld is, toegepast kan worden bij een ruimtelijk besluitvormingsproces op zee. Het gaat hierbij om twee workshops met belanghebbenden bij de ruimtelijke allocatie van offshore getijdecentrales rond de Mull of Kintyre in Schotland. De eerste workshop, de ‘lokale kennis’ workshop, had als doel het in kaart brengen van de kennis van belanghebbenden. Deze kennis wordt als waardekaarten weergegeven die vervolgens als input werd gebruikt bij de ‘onderhandelingsworkshop’. In deze workshop worden de waardekaarten op de Touch table gepresenteerd en door de deelnemers gebruikt om consensus te bereiken over mogelijke locaties voor de getijdecentrales. Ondanks een gebrek aan ervaring met deze aanpak, bleken de deelnemers in staat de instrumenten effectief te gebruiken in het onderhandelingsproces. De deelnemers kunnen met hulp van het instrument een aantal kaarten genereren met consensus locaties van getijdecentrales. Uit de workshops blijkt dat de aanpak waarbij deelnemers bij elkaar zitten om de kaarten collectief te manipuleren de deelnemers heeft geholpen bij het afbreken van grenzen en het aanmoedigen van samenwerking.

De hoofdconclusie van dit proefschrift is dat de voorgestelde onderzoeksmethode een participatief ruimtelijk besluitvormingsproces met conflicterende interesses van belanghebbenden succesvol kan ondersteunen. De gebruikte combinatie van op digitale kaarten gebaseerd instrumenten, de Touch table en participatieve workshops is effectief om zowel specifieke stadia als het gehele proces te ondersteunen. Dit is mogelijk door: 1) specifieke instrumenten aan de Touch table te koppelen; 2) bij specifieke workshops in te zetten; en 3) de resultaten van een workshop als input voor een volgende te gebruiken.

Een tweede conclusie is dat elke workshop uniek is met betrekking tot de doelen, geschikte deelnemers, opdrachten en de te gebruiken instrumenten. Voor het beginstadium van het besluitvormingsproces is een ontwerpworkshop geschikt waarbij tekeninstrumenten de communicatie tussen belanghebbenden ondersteund wordt. Tijdens een vervolgende analyseworkshop wordt een combinatie van multicriteria analyse met expertkennis en de Touch table een zinnig middel om ruimtelijke plannen te beoordelen op basis van verschillende criteria die relevant zijn voor een gebied. Voor het eindstadium van het proces komt een onderhandelingsworkshop in aanmerking. De gezamenlijke ruimtelijke allocatie van functies wordt ondersteund door middel van een combinatie van multicriteria analyse en een onderhandelingsmodule die geschikte locaties op de Touch table-kaart identificeert en vervolgens markeert.

Een derde conclusie is dat de Touch table een effectief instrument is om bij planningsworkshops te gebruiken. De Touch table is vooral effectief bij ruimtelijke besluitvormingsprocessen waarbij veel informatie beschikbaar is, er verschillende bronnen van expertkennis zijn en conflict bestaan tussen de belangen van verschillende actoren. Een zinvolle toepassing van de voorgestelde aanpak vereist een op consensus gerichte houding van de deelnemers die bereid zijn om naar elkaar te luisteren en kennis met elkaar te delen.

Resumen en español

Herramientas de soporte a toma de decisiones para planeamiento participativo de uso de suelo

Las actividades humanas relacionadas con la transformación de entornos naturales en áreas desarrolladas han contribuido de manera fundamental al aumento de la población del planeta y, por consiguiente, a su estado climatológico actual. A pesar de su creciente escasez para desarrollo, el territorio, ya sea natural, urbano o marítimo, se ha convertido en un recurso esencial para el desarrollo de actividades humanas a nivel mundial, particularmente en áreas de alta densidad de población.

La gestión de planes de ordenamiento territorial, ya sea para organizar las actividades humanas a nivel rural, urbano o regional, requiere no solo de decisiones colectivas sino también una ponderación cuidadosa y balanceada de las metas a corto y largo plazo en el contexto de sostenibilidad ambiental, social y económica. Lograr metas de sostenibilidad en un planeta de población creciente y territorio limitado aún se mantiene como un desafío científico que involucra diversas disciplinas, en especial planeamiento espacial. A pesar de importantes y recientes avances de investigación en el campo de sistemas informáticos de soporte de planeación, aún hacen falta métodos robustos que provean soporte adecuado a procesos de planeamiento territorial que involucran diferentes tipos de actores y disciplinas.

Esta tesis se enfoca en el desarrollo, evaluación y aplicación práctica de un sistema de herramientas de soporte a toma de decisiones que facilita la colaboración y el trabajo grupal alrededor de mapas digitales. Se propone un método investigativo que facilita el uso e implementación de este tipo de herramientas en el marco de un proceso participativo de planeamiento territorial, caracterizado por la existencia de conflictos de carácter espacial en los intereses de los actores involucrados. Dicho método está compuesto de tres elementos entrelazados, a saber: tres tipos de herramientas espaciales digitales, una mesa digital táctil interactiva y tres tipos de talleres de planeación. Las tres herramientas están diseñadas respectivamente para proveer soporte a tres tipos de actividades relacionadas con el planeamiento territorial, como son la comunicación, evaluación espacial y la modificación de la función del territorio, o uso de suelo. La mesa táctil es una pantalla digital de gran formato, sensible al tacto, que se opera mediante gestos. La mesa facilita el trabajo grupal orientado hacia el diseño, evaluación y modificación de planes de uso de suelo. Un taller de planeación se define como una reunión entre actores involucrados en la cual se discuten las funciones del territorio en cuestión. Los tres tipos de talleres hacen parte de una secuencia que comienza con un taller de diseño, continúa con un taller de análisis y termina con un taller de negociación.

El segundo y tercer capítulo de esta tesis se enfocan en el diseño técnico e informático de las herramientas y en su uso correspondiente. Más específicamente, el segundo capítulo describe los componentes de las herramientas de análisis espacial y presenta un ejemplo de implementación en un caso real de planeamiento de uso de suelo. Las herramientas de análisis espacial combinan análisis multicriterio con un sistema de información geográfica implementado en la mesa táctil. Estas herramientas se han desarrollado con el fin de facilitar la integración de conocimiento y experiencia de expertos provenientes de diversas disciplinas, relevantes para la valoración integrada de planes territoriales potenciales para una región. La valoración de un plan a nivel espacial se lleva a cabo tanto a un nivel general como a niveles específicos, es decir con base en criterios de evaluación previamente definidos. Las herramientas de

análisis facilitan la creación de un mapa de valoración para cada criterio. Cada uno de estos mapas muestra los efectos de un plan futuro medidos con base en un criterio específico. Las herramientas de análisis espacial son puestas a prueba en un taller de planeación en donde participan expertos involucrados en el proceso de reajuste territorial de un pólder (terreno húmedo ganado al mar) situado en los Países Bajos. Los participantes del taller tienen la oportunidad de interactuar con los mapas de valoración presentados en la mesa táctil, así como también de modificar los mapas existentes de manera colectiva y generar nuevos mapas de valoración. Usando las herramientas de evaluación, los participantes combinan los mapas de criterio de manera ponderada, con base en pesos específicos asignados para cada criterio, con el propósito de generar mapas integrados de valoración en el contexto de ambiciones normativas específicas para agricultura, suelo e hidrología, paisaje y naturaleza, así como también un mapa de valoración integral, que describe los efectos generales de planes futuros. En general, los mapas de valoración constituyen instrumentos efectivos para facilitar las discusiones y el diálogo entre expertos.

El tercer capítulo de esta tesis describe los componentes de una herramienta espacial diseñada para facilitar la adjudicación dialogada de funciones en un territorio. Esta herramienta hace uso de los mapas de valoración generados con las herramientas de análisis espacial descritas anteriormente, combinando esta información con el fin de resaltar áreas del territorio en las cuales se puedan realizar intercambios de funciones que mejoren la calidad del plan en cuestión. La herramienta permite que sus usuarios identifiquen en el mapa aquellas áreas negociables con el propósito final de facilitar la toma de decisiones grupales que permitan llegar a un consenso sobre las áreas cuyas funciones puedan ser intercambiadas. La herramienta se usa en combinación con la mesa táctil durante un taller de negociación en el que participan actores involucrados en el proceso de planeación del pólder. Con ayuda de las herramientas de negociación, los participantes logran diseñar un plan de uso de suelo más sostenible, es decir, de mayores calidades especificas e integradas que la situación actual del pólder. La herramienta permite que los participantes alcancen un cierto número de consensos reflejados en igual número de planes futuros para el pólder con calidades similares, a pesar de mostrar distribuciones diferentes de uso de suelo. Los participantes usan la herramienta de manera efectiva, incluso aquellos que no están familiarizados con análisis multicriterio, ya que consiguen entender las implicaciones de sus cambios de uso de suelo durante las negociaciones.

El cuarto capítulo de esta tesis hace énfasis en la evaluación sistemática de las herramientas de soporte a toma de decisiones y propone un método para la evaluación de la efectividad de las herramientas desarrolladas para el proceso de planeación del pólder. Mediante un análisis empírico se mide la efectividad de las herramientas con base en tres aspectos específicos, tales como: usabilidad, claridad e impacto en las decisiones tomadas. Las herramientas se ponen a prueba usando un grupo de control compuesto por estudiantes universitarios de maestría, a los cuales se les asignan papeles de actores reales involucrados en el proceso de planeación y se les solicita usar las herramientas con el propósito de completar un listado de tareas tanto individuales como grupales relacionadas con la asignación de uso de suelo al pólder. Treinta participantes logran diseñar 120 planes espaciales para el pólder. Durante los experimentos se recolectan datos relacionados con el desempeño de los participantes a través de cinco métodos: cuestionarios antes y después de los experimentos, anotaciones hechas por un observador, grabaciones de vídeo y los resultados de la valoración de calidad de los planes diseñados. El experimento arroja resultados a nivel individual y grupal, los cuales se analizan con base en la percepción de los participantes y en la calidad de los planes diseñados. El análisis empírico demuestra que los niveles de esfuerzo realizado por los participantes que usaron las herramientas están correlacionados con el formato de la información suministrada en las herramientas así como el nivel de detalle de la información.

El quinto y sexto capítulo describen dos aplicaciones prácticas del método propuesto en esta tesis. El quinto capítulo muestra la manera en que la secuencia de tres talleres de planeación es aplicada para proveer soporte al proceso de planeación de un pólder en los Países Bajos. Tres talleres de planeación (diseño, análisis y negociación) son organizados de manera consecutiva con actores involucrados en el proceso de planeación del pólder. Cada tipo de taller involucra metas, participantes, actividades y herramientas específicas. Asimismo, el capítulo explica la manera en que la información generada en un taller es usada en el siguiente. Los talleres demuestran que tanto el formato como el nivel de detalle de la información suministrada en la herramientas son aspectos importantes que deben ser específicos para cada taller.

El sexto capítulo describe una segunda aplicación práctica del método propuesto en esta tesis. Se demuestra cómo implementar el método, originalmente desarrollado para gestión de uso de suelo, en un proceso de toma de decisiones el contexto de planeación de espacios marítimos. Se describen dos talleres consecutivos organizados con actores involucrados e interesados en el proceso de adjudicación espacial en alta mar de dispositivos sumergidos que generan energía a partir de las mareas y corrientes submarinas, energía mareomotriz, en las aguas que rodean la península de Kintyre en Escocia. El objetivo del primer taller, llamado 'taller de conocimientos locales', consiste en elaborar de manera grupal un número de mapas de valoración que incluyan los conocimientos y experiencias de los participantes acerca del área de estudio. El resultado de este taller incluye un número de mapas de valoración, los cuales son usados en el siguiente taller, 'el taller de negociación'. En este segundo taller, los mapas de valoración son presentados a los participantes en la mesa táctil y posteriormente integrados en una herramienta de negociación que permite a los participantes alcanzar consensos relacionados con las posibles localizaciones de los dispositivos de generación de energía mareomotriz. A pesar de que los participantes no están familiarizados con el método, las herramientas son usadas de manera efectiva, lo cual permite llegar a consensos durante las negociaciones. Dichos consensos son reflejados en un listado de mapas con posibles localizaciones de los dispositivos de energía mareomotriz. En general, esta secuencia de talleres demuestra la efectividad del método propuesto en esta tesis para romper barreras entre participantes a través de la manipulación colectiva de mapas en la mesa táctil, así como para estimular la cooperación y el trabajo en equipo.

De esta tesis se derivan tres conclusiones principales. Primero, esta tesis concluye que el método de investigación propuesto puede proveer soporte efectivo a procesos de toma de decisiones espaciales en donde existe conflicto de intereses entre los actores involucrados. La combinación de mapas digitales, mesa táctil y talleres de planeación es efectiva para facilitar tanto la totalidad del proceso de decisión como cada etapa específica. Esto es posible a través de la integración de herramientas especificas con la mesa táctil en talleres específicos y del uso de los resultados obtenidos en un taller como datos de entrada para un siguiente taller.

La segunda conclusión de esta tesis está relacionada con los talleres de planeación y afirma que cada taller debe ser único en cuanto a metas, participantes, tareas a realizar, detalle de la información suministrada y herramientas a usar. Un taller de diseño es adecuado para etapas iniciales del proceso de planeación, en las cuales la comunicación y el diálogo entre actores son facilitados mediante el uso de herramientas de dibujo conectadas a la mesa táctil. La integración de análisis multicriterio con conocimiento de expertos en la mesa táctil durante un taller de análisis proporciona apoyo adecuado para la valoración de planes espaciales con base en criterios preestablecidos y relevantes para un área de interés. Un taller de negociación es adecuado para etapas finales del proceso de planeación. La adjudicación grupal de funciones de uso de suelo es facilitada mediante del uso de herramientas que combinan análisis de multicriterio y un módulo de negociación que muestra y resalta las localizaciones potenciales en la mesa táctil.

Como conclusión final, esta tesis afirma que instrumentos como la mesa táctil constituyen mecanismos efectivos para uso en talleres de planeación, particularmente en procesos territoriales que se caractericen por: 1) disponer de abundante información sobre el área a planear; 2) la participación de expertos en diversas disciplinas; y 3) la existencia de conflictos espaciales en los intereses de los diversos actores involucrados. Para garantizar el éxito del método propuesto en esta tesis, es esencial que el proceso sea incluyente y que exista una actitud dialogante entre los involucrados que permita el intercambio de ideas, experiencias y conocimientos.